

A Final Report to  
The California Air Resources Board  
Integrated Watershed Study

VEGETATION PROCESS STUDIES

CARB Contract No. A6-081-32

Philip W. Rundel

Donald J. Herman

Wade L. Berry

Ted V. St. John

Laboratory of Biomedical and Environmental Sciences  
900 Veteran Avenue  
Los Angeles, California 90024  
(213) 825-4072

Prepared April 15, 1989

#### ACKNOWLEDGEMENTS

We acknowledge with thanks the continuing cooperation and logistic support of the staff of Sequoia and Kings Canyon National Parks during this study. This support has been an essential element in the success of our research program. Our work could not have been carried out without the field assistance of a number of individuals over the five years of this project, and we are grateful for their efforts. Dr. Kathy Tonnessen of the California Air Resources Board has provided important discussions and guidance to our program of research.

This report was submitted in fulfillment of CARB contract number A6-081-32, "Vegetation Process Studies," by the Laboratory of Biomedical and Environmental Sciences, University of California, Los Angeles, under the partial sponsorship of the California Air Resources Board.

## DISCLAIMER

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

## TABLE OF CONTENTS

List of Figures . . . . .	v
List of Tables . . . . .	vi
Abstract . . . . .	1
Introduction . . . . .	3
Project Objectives . . . . .	4
Study Area . . . . .	5
Biogeochemical Aspects of Aluminum Cycling in a Sierran Subalpine Lake Watershed . . . . .	8
Introduction . . . . .	8
Materials and Methods . . . . .	8
Results and Discussion . . . . .	15
Summary . . . . .	23
Red Fir Response to Rhizosphere Changes in pH and Aluminum . . . . .	27
Materials and Methods . . . . .	27
Results and Discussion . . . . .	31
Vegetation Units in the Emerald Lake Basin . . . . .	45
Association Descriptions . . . . .	46
Methods of Community and Watershed Nutrient Analysis . . . . .	54
Community and Watershed Nutrient Pools and Fluxes . . . . .	65

## LIST OF FIGURES

1. Vegetation unit map of Emerald Lake Watershed . . . . .	6
2. Conceptual model of Al flow through Emerald Lake Watershed . . .	14
3. Diagram of rhizotron used for monitoring and recording root elongation . . . . .	14
4. Response of <u>A. magnifica</u> roots to pH of nutrient solution, 0.01 $\mu\text{M}$ Al . . . . .	21
5. Response of <u>A. magnifica</u> roots to pH of nutrient solution, 10 mM Al . . . . .	21
6. Response of <u>A. magnifica</u> roots to $\text{Al}^{3+}$ in nutrient solutions at pH 5.0 . . . . .	22
7. Solubility of Al in two Emerald Lake Watershed soils . . . . .	22
8. Growth rate of <u>Abies magnifica</u> root in rhizotron during 5.5 hour monitoring . . . . .	35
9. Responses of <u>Abies magnifica</u> roots to gradual lowering of nutrient solution pH in the presence of background Al levels .	36
10. Response of <u>Abies magnifica</u> roots to pH 3.8 nutrient solution .	41
11. Responses of <u>Abies magnifica</u> roots to gradual lowering of nutrient solution pH in the presence of 10 mM total Al . . . . .	42
12. Response of <u>Abies magnifica</u> roots to $\text{Al}^{3+}$ in nutrient solutions of constant pH 5.0 . . . . .	44

## LIST OF TABLES

1. Regressions for estimating biomass and productivity of <u><i>Pinus monticola</i></u> . . . . .	10
2. Biomass and Al pools of vegetation and soils at Emerald Lake watershed . . . . .	16
3. Biomass productivity and Al fluxes of vegetation at Emerald Lake watershed . . . . .	17
4. Relative abundance of colluvium species . . . . .	51
5. Relative plant cover of the colluvium . . . . .	52
6. Mean mapped area of major vegetation units within the Emerald Lake Basin and mean coverage of plant groups within these mapped units . . . . .	53
7. Notes for the sources of data presented in the biomass and nutrient pool tables for the Emerald Lake Basin . . . . .	60
8. Footnotes for Table 7 . . . . .	63
9. Above-ground, below-ground, and litter biomass for vegetation types within the Emerald Lake Watershed . . . . .	68
10. Above-ground and litter productivity for vegetation types within the Emerald Lake Watershed . . . . .	68
11. Net annual uptake of nitrogen by above-ground and litter for vegetation types within the Emerald Lake Watershed . . . . .	69
12. Net annual uptake of phosphorus by above-ground and litter for vegetation types within the Emerald Lake Watershed . . . . .	69
13. Emerald Lake Trees: Total biomass and mineral concentrations . .	70
14. Emerald Lake Willows: Biomass density and mineral concentrations .	71
15. Emerald Lake Mesic Rock Crevices: Biomass density and mineral concentrations . . . . .	76
16. Emerald Lake Mesic Shrubs: Biomass density and mineral concentrations . . . . .	77
17. Emerald Lake Wet Meadow Herbs: Biomass density and mineral concentrations . . . . .	81
18. Emerald Lake Xeric Rock Crevices: Biomass density and mineral concentrations . . . . .	85

LIST OF TABLES (continued)

19.	Emerald Lake Dry Meadow: Biomass density and mineral concentrations . . . . .	86
20.	Emerald Lake Fell Field: Biomass density and mineral concentrations . . . . .	88
21.	Emerald Lake Colluvium: Biomass density and mineral concentrations . . . . .	90
22.	Emerald Lake Willows: Biomass and mineral capitals, community basis . . . . .	92
23.	Emerald Lake Mesic Shrubs: Biomass and mineral capitals, community basis . . . . .	94
24.	Emerald Lake Mesic Rock Crevices: Biomass and mineral capital, community basis . . . . .	96
25.	Emerald Lake Wet Meadow Herbs: Biomass and mineral capitals, community basis . . . . .	97
26.	Emerald Lake Xeric Rock Crevices: Biomass and mineral capitals, community basis . . . . .	98
27.	Emerald Lake Dry Meadows: Biomass and mineral capitals, community basis . . . . .	99
28.	Emerald Lake Fell Field: Biomass and mineral capital, community basis . . . . .	100
29.	Emerald Lake Colluvium: Biomass and mineral capitals, community basis . . . . .	101
30.	Emerald Lake Willows: Productivity and mineral fluxes, community basis . . . . .	102
31.	Emerald Lake Mesic Shrubs: Productivity and mineral fluxes, community basis . . . . .	104
32.	Emerald Lake Mesic Rock Crevices: Productivity and mineral fluxes, community basis . . . . .	106
33.	Emerald Lake Wet Meadow Herbs: Productivity and mineral fluxes, community basis . . . . .	107
34.	Emerald Lake Xeric Rock Crevices: Productivity and mineral fluxes, community basis . . . . .	108

LIST OF TABLES (continued)

35. Emerald Lake Dry Meadows: Productivity and mineral fluxes, community basis . . . . .	109
36. Emerald Lake Fell Fields: Productivity and mineral fluxes, community basis . . . . .	110
37. Emerald Lake Colluvium: Productivity and mineral fluxes, community basis . . . . .	111
38. Emerald Lake Trees: Biomass and mineral capitals, whole-watershed basis . . . . .	112
39. Emerald Lake Willows: Biomass and mineral capitals, whole-watershed basis . . . . .	113
40. Emerald Lake Mesic Shrubs: Biomass and mineral capitals, whole-watershed basis . . . . .	115
41. Emerald Lake Mesic Rock Crevices: Biomass and mineral capitals, whole-watershed basis . . . . .	117
42. Emerald Lake Wet Meadow Herbs: Biomass and mineral capitals, whole-watershed basis . . . . .	118
43. Emerald Lake Xeric Rock Crevices: Biomass and mineral capitals, whole-watershed basis . . . . .	119
44. Emerald Lake Dry Meadows: Biomass and mineral capitals, whole-watershed basis . . . . .	120
45. Emerald Lake Fell Fields: Biomass and mineral capitals, whole-watershed basis . . . . .	121
46. Emerald Lake Colluvium: Biomass and mineral capitals, whole-watershed basis . . . . .	122
47. Emerald Lake Trees: Productivity and mineral fluxes, whole-watershed basis . . . . .	123
48. Emerald Lake Willows: Productivity and mineral fluxes, whole-watershed basis . . . . .	124
49. Emerald Lake Mesic Shrubs: Productivity and mineral fluxes, whole-watershed basis . . . . .	126
50. Emerald Lake Mesic Rock Crevices: Productivity and mineral fluxes, whole-watershed basis . . . . .	128

## LIST OF TABLES (continued)

51. Emerald Lake Wet Meadow Herbs: Productivity and mineral fluxes, whole-watershed basis . . . . .	129
52. Emerald Lake Xeric Rock Crevices: Productivity and mineral fluxes, whole-watershed basis . . . . .	130
53. Emerald Lake Dry Meadows: Productivity and mineral fluxes, whole-watershed basis . . . . .	131
54. Emerald Lake Fell Fields: Productivity and mineral fluxes, whole-watershed basis . . . . .	132
55. Emerald Lake Colluvium: Productivity and mineral fluxes, whole-watershed basis . . . . .	133

## ABSTRACT

In this final project report, preceded by two final contract reports in previous years, we have focused on aluminum specifically as potentially significant trace element in the terrestrial mineral fluxes of the Emerald Lake basin, and additionally dealt more broadly with the pool sizes and fluxes for all of the major macronutrients, cations and trace elements in the terrestrial vegetation of this basin.

The 1206 conifers in the basin are scattered in occurrence, but form the major part of the plant biomass. These conifers comprise 90% of the above-ground biomass in the basin, 73% of the below-ground biomass, and are associated with 5% of the litter biomass. Overall, conifers comprise 85% of the 25.65 metric tons of biomass present. In terms of net annual productivity, the conifers are somewhat less important but still comprise the dominant vegetation unit in terms of biological activity. Conifers account for 62% of net above-ground productivity, more than four times the values for the willow and wet meadow communities which are also significant. Together these three communities account for 90% of the basin-wide, above-ground, net primary productivity. Our below-ground values of net productivity remain with a high uncertainty value, and almost certainly overestimate the levels of growth, particularly for the willow community.

Investigations of biogeochemical aspects of aluminum cycling through the terrestrial compartments of the Emerald Lake watershed have established that several communities appear to be rapidly aggrading and accumulating aluminum. Aluminum is released into the soil primarily by the weathering of gibbsite and hydroxy interlayer vermiculite in acid soils. Free Al<sup>3+</sup> in the soil solution is controlled by weathering and release reactions, but some of this

$\text{Al}^{3+}$  is absorbed by vegetation. Most of the observed net accumulation of aluminum in vegetation is associated with below-ground tissues, rather than above-ground tissues, this may represent some degree of soil contamination. Overall, aluminum cycling in the watershed is conservative.

No evidence exists to suggest that soil acidity itself is adversely affecting plant growth in the basin. Soil pH in the basin range from 4.0 to 5.5 for the typic cryorthod unit comprising much of the Pinus monticola stands. This value seems to be within the pH tolerance range for these conifers. Acidity may, however, have the potential to cause a secondary effect on aluminum solubility which could impact conifer roots. Laboratory experiments with red fir suggest that growth rates of conifer roots may be suppressed in the presence of  $\text{Al}^{3+}$  levels similar to those measured in soils of the Emerald Lake basin.

Field studies and laboratory analyses have been used to quantify standing biomass, net annual primary production, vegetation mineral pool sizes, and vegetation mineral flux rates for nine major plant communities in the Emerald Lake watershed. For conifers, these data are based on a complete census of all trees in the basin. For the other eight communities data were calculated per unit area of that community type and for the basin as a whole.

Data for biomass and nutrient pool sizes have been estimated from a variety of both direct measurements and extrapolations from other data (see text). Productivity and nutrient flux data are considered to be accurate for above-ground tissues, but less reliable for below-ground tissues because of inherent problems in sampling these tissues. Root tissues are a very important component of the biological activity of the basin. Although they comprise less than 30% of the existing biomass, we estimate that such tissues comprise 60-70% of the net primary production.

## INTRODUCTION

This report covers our third period of work on vegetation processes at Sequoia National Park, carried out between October 1, 1986 and December 31, 1988. Our work was undertaken as a study of the base level processes of growth and nutrient dynamics that may be influenced in coming years by acid deposition.

Detrimental effects have been documented elsewhere and have been described in reviews and symposia by Mudd and Kozlowski (1975), Hutchinson and Havas (1980), Miller (1980), and Smith (1981). Although experimental work to date has been primarily in Europe and the eastern United States, acid deposition has been shown to occur in California (Lawson and Wendt 1982). The Sierra Nevada lie in the path of pollutant-laden air from major metropolitan areas, and include the most sensitive regions of California. There is ample reason to expect future effects on tree growth and vigor phenology, soil chemistry, soil microbiology, and nutrient cycling processes (Alexander 1980, McColl 1981b, Hutchinson and Havas 1980). Acid deposition in California differs from that in Europe and the Eastern United States, in that a larger proportion is left as dry deposition and there appears to be a higher ratio of  $\text{NO}_x$  to  $\text{SO}_x$  here.

Net primary productivity (NPP), the ecosystem-level expression of forest growth, is a fundamental process that is sensitive to any stress-inducing environmental factor. The effects of acid deposition and air pollution in California are likely be seen in declines in forest productivity. Smith (1981) listed recent papers documenting effects of these influences on forest growth. The mechanisms by which acid deposition and air pollution may suppress NPP include both direct and indirect pathways. The direct pathways are those involving increased physiological stress and tissue damage; they have been

discussed by Jacobson (1980). The indirect pathways usually involve soil processes. Damage to roots and symbionts, while often difficult to detect and quantify, may be the earliest manifestations of pollution-related damage to forests. One example of such damages is the effect of aluminum on roots (Foy 1974). Aluminum has been reported by Ulrich (1983) to sometimes accumulate to toxic levels in soils subject to acid precipitation.

Not only roots, but the vital root symbionts known as mycorrhizae may be damaged. Both vesicular-arbuscular mycorrhizae (VAM) and ectomycorrhizae (ECM) may be ~~intolerant~~ of pH changes (Mosse 1975, Graw 1979, Bauch 1983, Marx and Krupa 1978). Further, VAM fungi may be intolerant of low levels of toxic elements (Killham and Firestone 1983, Gildon and Tinker 1983a, b, McCool and Menge 1983, Trappe et al. 1973). There may also be damage to the nonsymbiotic, but still vital, microflora and microfauna that carry out the processes of decomposition and mineralization of nutrient elements (Coleman 1983). Such damage could be brought about by the changes in soil chemistry and increases in aluminum ion concentration thought to attend prolonged exposure to acid deposition. Among the possible modifications to essential element cycles are inhibition of nitrogen fixation and inhibition of nitrogen transformation (Seip and Freedman 1980, Strayer et al. 1981, Cook 1983). There may also be decreases in the availability of phosphorus linked to any changes in soil pH (Cook 1983).

#### Project Objectives

Our specific objectives in this project have been to establish baseline levels of above-ground and below-ground production, against which future changes due to acid deposition and air pollution may be assessed and to quantify the

nutrient pools and fluxes in the Emerald Lake Basin. Concisely stated, the objectives for this project over its full period have been

- ..to establish quantitative baseline data on above-ground NPP for the dominant species at Emerald Lake;
- ..to establish quantitative baseline data on below-ground NPP by fine roots and mycorrhizae for the dominant species at Emerald Lake;
- ..to determine pool sizes and fluxes of nitrogen, phosphorus, sulfur, aluminum and other important cations in terrestrial vegetation;
- ..to aid in the production of a quantitative model of terrestrial element cycles, as a portion of a model of watershed processes;
- ..to characterize the community types and the species composition of the important terrestrial vegetation types at Emerald Lake.
- ..to aid in the production of a quantitative model of terrestrial element cycles, as a contribution to models of watershed processes.

In this final project report we focus on the integrated results of our data on element pools and fluxes within vegetation units of the Emerald Lake Basin.

#### Study Area

Emerald Lake at 2800 m elevation is the subalpine site used by this and related studies (Figure 1). It occupies a granitic drainage about 125 ha in size. The Emerald Lake watershed includes permanent vegetation plots, a gauging station, rain gauges, and a meteorological station. Most of the terrain at Emerald Lake consists of variously jointed exposures of granodiorite. Most of

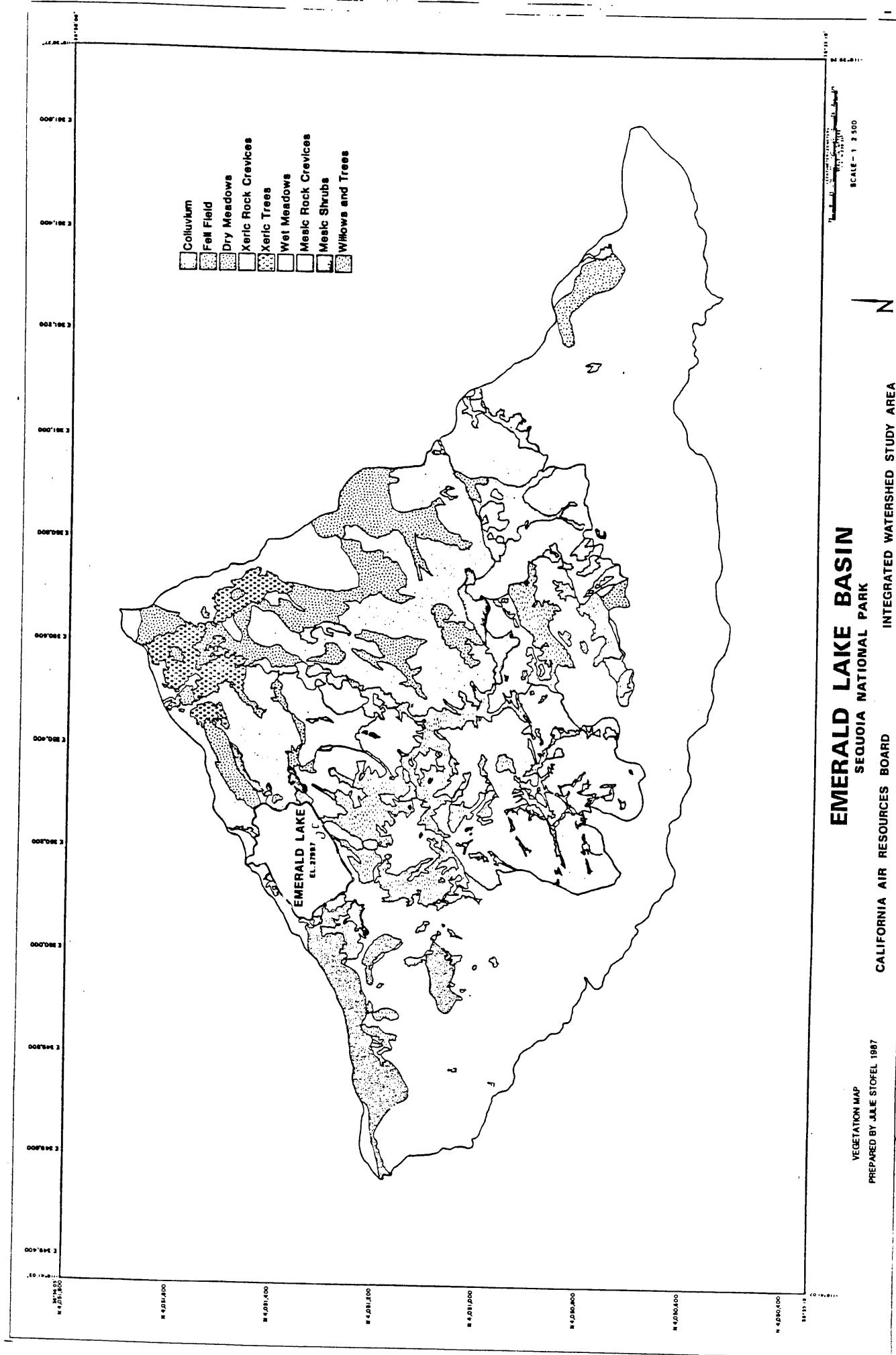


Figure 1. Vegetation unit map of Emerald Lake watershed.

the soils have formed in localized regions defined by rock joints. All have a cryic temperature regime and sandy or coarse-loamy textures. Most are classified as lithic cryumbrepts and entic cryumbrepts. Soil depths to underlying rock range from 10 to 50 cm.

Vegetation is sparse and much of the basin is exposed granite. Coniferous trees occur in scattered clumps. The species include Pinus contorta var. murrayana (lodgepole pine), P. monticola (western white pine), P. jeffreyi (Jeffrey pine), and P. balfouriana (foxtail pine). Locally common shrubs are Phyllodoce breweri, Chrysolepis sempervirens, and Salix oreastera. Four vegetation types at Emerald Lake have been identified as recipients of detailed study. The choice was based on their relative importance in terms of surface area and biomass. The first of these is designated as "wet meadow." It is a mixture of grasses and herbs in a mesic setting, and has been referred to in our internal communications and notes as "GHM." The second is "willow thicket," composed largely of Salix oreastera, which has in certain other documents, been called by an acronym for the dominant species "SAOR." The next is a heather scrub, which will be referenced here by the dominant species Phyllodoce breweri (PHBR). The last vegetation type, also denoted by its dominant species, is Chrysolepis sempervirens (CHSE). The structure and diversity of plant communities within the Emerald Lake basin is discussed in more detail later in this report.

## Biogeochemical Aspects of Aluminum Cycling in a Sierran Subalpine Lake Watershed

### INTRODUCTION

Acid precipitation has been linked to deleterious effects on vegetation growing in impacted areas (Hutchinson and Havas 1980; Miller 1980; Mudd and Kozlowski 1975; Smith 1981). There is evidence indicating that many soils of the Sierra Nevada in California are currently receiving moderate levels of acid deposition, but are highly susceptible to damage should levels increase (Calif. Air Resources Board 1988a, b). One mechanism by which this is thought to impact plants is through the increased abundance of toxic Al<sup>3+</sup> present at lower soil pH (Ulrich 1983). It therefore becomes of interest to evaluate the degree to which sensitive Sierran ecosystems may be at risk to Al phytotoxicity. This research was undertaken to identify major pools and pathways of Al cycling in these systems and to evaluate how pH-induced changes in Al speciation and mobility may affect vegetation of this ecosystem.

### MATERIALS AND METHODS

#### Field Studies

Emerald Lake watershed (ELW) is located in Sequoia National Park in California's southern Sierra Nevada at 2800 m elevation. It occupies a granitic drainage about 120 ha in area. Approximately 75% of the watershed's vegetation may be accounted for by three major communities: Pinus monticola, Salix oreastera, and wet meadow. These communities occupy areas of 2.47, 8.55, and 4.14 ha, respectively. The soil map units which roughly correspond to these

three communities are Typic Cryorthod-rock outcrop (TdoF-R), Entic Cryumbrept (EaD), and Lithic Cryumbrept-rock outcrop (LeC-R), respectively (Huntington and Akeson 1987).

The experiment was designed to estimate the standing biomass and pool sizes of Al in the water, soil, and vegetation of the watershed, and to monitor fluxes of Al among these pools (Figure 2). Standing pools were estimated from measurements conducted in 1985 or 1986; fluxes were estimated as the difference in pool size measured in two years.

Twelve profiles of each of the three soils associated with the three plant communities were sampled randomly in 1986. The amorphous aluminum hydroxide ( $\text{Al(OH)}_3$  amorph.) in the soils was measured by extraction with hydroxylamine hydrochloride (Lund et al. 1989). Standing pools of soil Al were estimated assuming  $\text{Al(OH)}_3$  (amorph.) is the solid phase most likely to release  $\text{Al}^{3+}$  to the soil solution.

Aboveground biomass of the P. monticola community was estimated by measuring diameter at breast height (dbh) of each individual in the watershed and applying regressions developed for a similar species, Pinus lambertiana (Gholz et al. 1979) (Table 1). Fine root (<2 mm) and woody root (>2 mm) biomass was estimated as 6% and 20%, respectively, of total biomass Pearson et al. 1984). Annual productivity was estimated as a percent of standing biomass using parameters developed for Sierran Abies species (Westman 1987) (Table 1). Litter residence time (years) was estimated from the function:

$$y_t = y_0 \exp(-0.0943) \quad (1)$$

developed from Pinus jeffreyi (Stark 1972).

Table I. Regressions for estimating biomass and productivity of Pinus monticola. For biomass, the dependent (Y) variable is dry weight (kg) and independent variable (X) is dbh (cm). Productivity is calculated as a percent of biomass.

Tissue	Biomass	Productivity
Foliage	$Y = 0.0179X^{2.0327}$	7.74%
Live branch	$Y = 0.0004823X^{3.3648}$	5.49%
Stem wood	$Y = 0.01861X^{2.6667}$	1.38%
Stem bark	$Y = 0.005017X^{2.6186}$	1.42%
Fine roots		4.01%
Woody roots		4.01%

Biomass samples of 1 m<sup>2</sup> canopy areas for S. orestera were collected in 1985 and separated into current-year and old foliage, current-year and old twigs, reproductive tissue, dead wood, and older woody tissue. In 1986 branches were sampled from ground level to determine new production. Eight, 10, or 20 cm diameter soil cores were sampled in July and late season in 1985 and 1986. Root biomass was determined for < 2 mm, 2-5 mm, 5-10 mm, 10-20 mm, and 20-50 mm size classes. Annual root production was estimated using the sum of biomass increments between the July, 1985 and July, 1986 sampling dates.

Aboveground biomass samples from two 0.0314 m<sup>2</sup> plots were collected from each major subtype in the wet meadows. Annual production was estimated by separating current year from previous growth. Root biomass and production was determined as for S. orestera.

Aluminum content of live biomass of the three vegetation types and litter of the wet meadow communities was measured in tissue collected from the watershed in 1985 through 1988. Samples were dried and finely ground, and multi-element assays were conducted by direct combustion using an optical emission spectrometer calibrated with NBS Standard Reference Material 1. Aluminum content of zeroth-year P. monticola litter was assumed equal to Al content of live needles; Al in standing P. monticola litter was summed from the zeroth-year litter over the residence time of litter estimated from equation 1. It was assumed that the litter:leaf Al concentration ratio measured in wet meadow vegetation would approximate that of Salix; Al concentration of Salix litter was estimated multiplying Salix leaf Al concentration by that ratio.

Fluxes of Al into live biomass were estimated from multiplying the Al content of a tissue by the productivity of the tissue. Flux of Al into Salix and Pinus litter was estimated from multiplying the Al content of the litter source (foliage) by the annual litter-fall.

Samples of four ELW soils were subjected to varying concentrations of HCl in a month-long weathering experiment (Lund et al. 1989). Soluble Al was measured by inductively-coupled plasma emission spectroscopy. The free Al<sup>3+</sup> and solubility of gibbsite ( $\text{gamma-Al(OH)}_3$ ) was calculated using the solubility constants of Hedges (1987).

Researchers from the University of California, Santa Barbara monitored lake inflow and outflow water volumes during the ice-free and snowmelt season (Dozier et al. 1987; Melack et al. 1987; Melack et al 1989). Unfiltered water samples were collected for Al analyses and preserved in 0.1 N HNO<sub>3</sub> (Ultrex). Samples were stored at 4°C until analysis, and analysis was performed using graphite-furnace, atomic-absorption spectrophotometry.

To estimate Al transport from the watershed, Al concentration of inflow water should be multiplied by the annual inflow volume; however, inflow volume data are incomplete. Inflow volume may be estimated assuming it equals outflow volume plus lake surface evaporation. Assuming further that evaporation is a negligible fraction of total flux, inflow volume is approximately equal to outflow volume. Since outflow volume data are complete for three water years, these are substituted for inflow volumes in subsequent computations. Aluminum loss from the watershed was estimated averaging unfiltered Al concentration of inflow water over the 1984-1987 sampling years, averaging the annual outflow volume over the 1984-1986 water years, and computing the product of these two means.

#### Aluminum Dose-Response-Curves

Three year old seedlings of Abies magnifica, a species found in the watershed, were subjected to varying levels of pH and Al<sup>3+</sup> to determine their main effects and interactions on root growth. An active root of a seedling was

exposed and placed in the flow cell of a specially designed rhizotron (Figure 3). A 10% Ingestad's solution (Ingestad 1962) containing either 0.01  $\mu\text{M}$  or 10  $\text{mM}$  Al as  $\text{Al}_2(\text{SO}_4)_3$  was adjusted to a pH between 6.2 and 6.5 and passed through the flow cell. The root tip was monitored through a microscope and video camera, the image digitized, and root elongation was recorded. A typical growth rate of the control roots was  $4 \mu\text{m} \cdot \text{min}^{-1}$ . When the elongation rate had stabilized, a low pH solution was slowly pumped into the primary solution, thereby gradually lowering the pH of the solution passing the root to pH 2.5. The solution pH was measured as it drained from the flow cell, and was recorded along with root elongation. Thus, real-time response of root growth to solution pH was measured.

The low-acid solutions (pH 6.2 to 6.5) served as the controls for these experiments. Since mean growth rates of the controls varied from 1 to  $5 \mu\text{m} \cdot \text{min}^{-1}$  among the roots we worked with, normalizing the growth rates allowed comparisons among replicates and across treatments. Relative growth rate (RGR) was defined as the measured growth rate divided by the mean growth rate for that root in the control solution.

To estimate the concentration of free  $\text{Al}^{3+}$  (the most probable plant-available Al form (Pavan and Bingham 1982)) in the nutrient solutions, the chemical equilibria model GEOCHEM was applied (Chaney 1988). Using the GEOCHEM model a curve was developed for the pH range of 2.5 to 6.5 in 0.1 pH unit increments which produced the  $\text{pAl}^{3+}$  (the negative log of the solution  $\text{Al}^{3+}$  concentration) for our experimental pH conditions.

In a second experiment the response of roots to varying levels of Al in solutions of constant pH (5.0) was tested. Total Al ranged from  $10^{-2}$  to  $10^4 \mu\text{M}$ . In control solutions of pH 6.2 free  $\text{Al}^{3+}$  ranged from  $10^{-6}$  to  $10^{-2} \mu\text{M}$  and in the pH 5.0 solutions it ranged from  $10^{-3}$  to  $10^2 \mu\text{M}$ . Roots

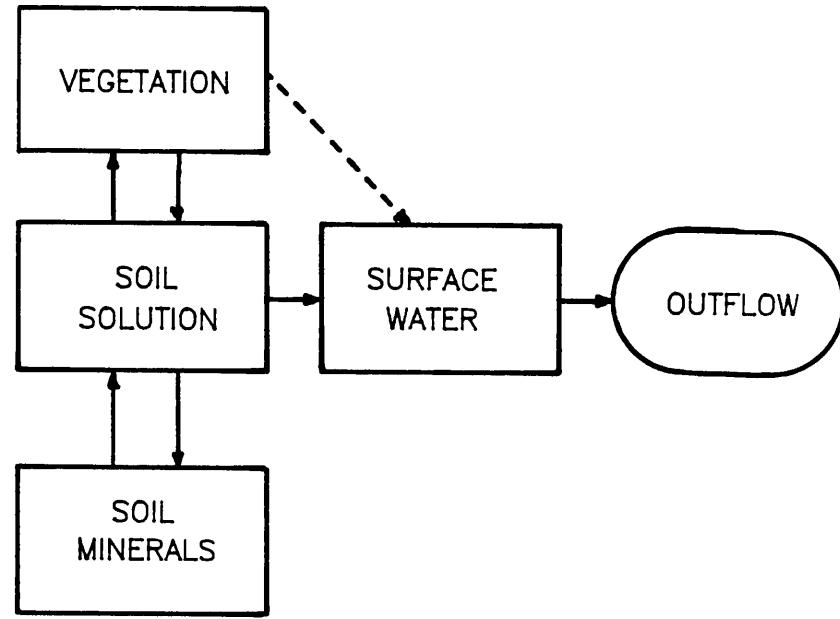


Figure 2. Conceptual model of Al flow through Emerald Lake Watershed.

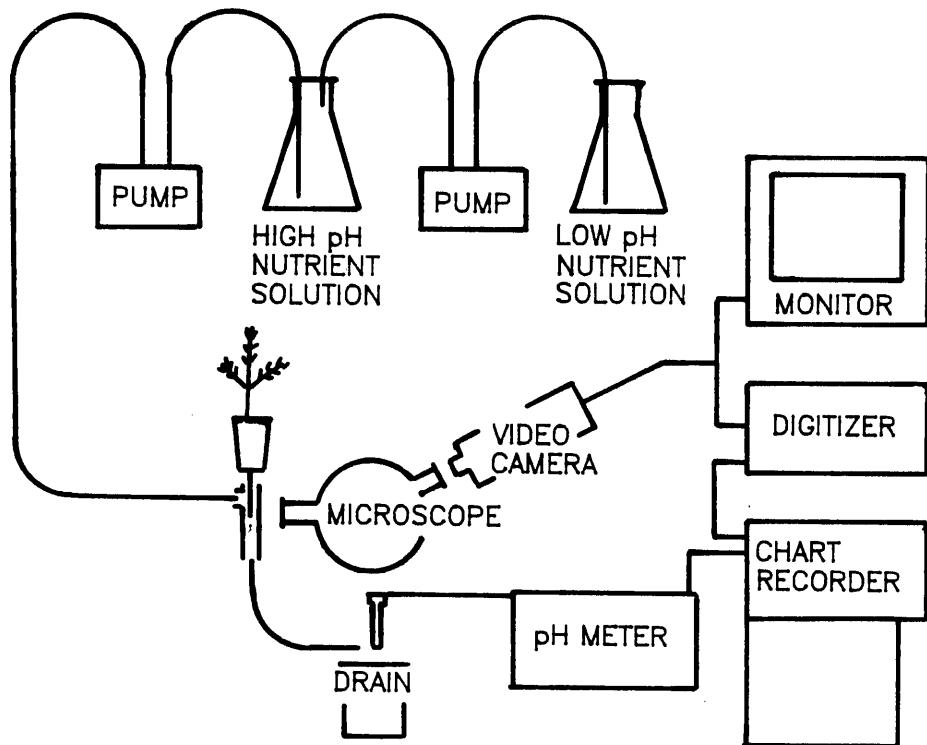


Figure 3. Diagram of rhizotron used for monitoring and recording root elongation.

were placed in the rhizotron, exposed to the control nutrient solution, and monitored until a stable growth rate was achieved. Growth rate in the control solution was then recorded for 30 min., then the root was exposed to an equal total Al level, but at pH 5.0. After growth rate had stabilized under these new conditions, it was recorded for 30 minutes. Growth rates for comparison purposes were normalized to RGR as described above.

## RESULTS AND DISCUSSION

### Aluminum Cycling

Pinus monticola represented 76% of the total biomass in the three communities, with  $19000 \text{ kg} \cdot \text{ha}^{-1}$  of biomass on a whole-watershed basis (Table 2). Salix oreastera and wet meadow communities followed with 4400 and  $1500 \text{ kg} \cdot \text{ha}^{-1}$ , respectively. Most of the biomass in the P. monticola group was contained in the stem and branch fractions; the foliage biomass was only moderately higher than foliage of Salix or wet meadow herbs.

Productivity data (Table 3) indicate a large aggradation of all communities. This may in part result from inaccurate estimates of litter production. Large stems were not included in estimates of Pinus litter, so it may be expected that reported litter data underestimate actual litter inputs. The large root net productivity may have resulted from unquantified inaccuracies in the methodology. Inaccurate estimates of root production and turnover could result from non-uniformity of root sizes, the separation of roots from soil, the variable and localized nature of growth and death processes, and differentiating live from dead roots (Fogel 1985).

Aluminum pools were higher in the belowground than aboveground pools of all groups (Table 2); however, this may reflect incomplete removal of soil material

Table 2. Biomass and Al pools of vegetation and soils at Emerald Lake watershed.

Tissue	---- Biomass -----		Al -----		
	(Mg/ha) (community)	(Mg/ha) (basin)	(µg/g)	(kg/ha) (community)	(kg/ha) (basin)
<b><u>Salix oreastera</u></b>					
Aboveground					
Current twigs + stems	0.619	0.044	31	0.02	0.001
Dead wood	11.300	0.805	63	0.71	0.050
New leaves	0.757	0.054	105	0.08	0.006
Old twigs	19.600	1.390	8	0.16	0.012
Reproductive	0.048	0.003	166	0.01	0.001
Litter	14.400	1.030	483	6.96	0.496
Sum:	46.700	3.330		7.94	0.565
Belowground					
< 2 mm	6.130	0.437	11800	72.30	5.150
2 - 5 mm	1.400	0.100	5540	7.81	0.556
5 - 10 mm	2.010	0.143	6070	12.20	0.869
10 - 20 mm	1.910	0.136	1750	3.34	0.238
20 - 50 mm	3.310	0.236		0.00	0.000
Sum:	14.800	1.050		95.70	6.820
Soil Al(OH) <sub>3</sub> (amorph.)			22000	22600.00	1610.000
<b><u>Pinus monticola</u></b>					
Aboveground					
Foliage	15.400	0.317	352	5.42	0.111
Live branch	266.000	5.470	265	70.50	1.450
Stem wood	330.000	6.790	119	39.30	0.809
Stem bark	70.500	1.450	323	22.80	0.469
Litter	4.520	0.093	1560	7.03	0.145
Sum:	686.000	14.100		145.00	2.980
Belowground					
Fine (<2mm) roots	55.300	1.140	6450	357.00	7.340
Woody roots	184.000	3.790	3050	563.00	11.600
Sum:	240.000	4.930		919.00	18.900
Soil Al(OH) <sub>3</sub> (amorph.)			13400	18000.00	370.000
<b>Wet Meadow Herbs</b>					
Aboveground					
Standing	3.530	0.122	922	3.26	0.112
Litter	1.370	0.047	4200	5.76	0.199
Sum:	4.900	0.169		9.01	0.311
Belowground					
Soil Al(OH) <sub>3</sub> (amorph.)	37.600	1.300	7640	287.00	9.910
Grand Total (Vegetation)			13200	17900.00	617.000
Grand Total (Soil)					39.500
					2600.000

Table 3. Biomass productivity and Al fluxes of vegetation at Emerald Lake watershed.

Tissue	--- Productivity ---		----- Al -----	
	--- (Mg/ha/yr) ---	(community) (basin)	( $\mu\text{g/g}$ )	--- (kg/ha/yr) ---
			(community)	(basin)
<b><u>Salix oreastera</u></b>				
Aboveground				
Current twigs + stems	1.510	0.107	31	0.05
New leaves	1.230	0.088	105	0.13
Litter	-0.183	-0.013	105	-0.02
Net:	2.560	0.182		0.16
Belowground				
< 2 mm	2.850	0.203	11800	33.60
2 - 5 mm	0.441	0.031	5540	2.44
5 - 10 mm	2.680	0.191	6070	16.30
10 - 20 mm	1.640	0.117	1750	2.87
20 - 50 mm	3.580	0.255		0.00
Net:	11.200	0.797		55.20
<b><u>Pinus monticola</u></b>				
Aboveground				
Foliage	1.190	0.025	352	0.42
Live branch	14.100	0.290	265	3.73
Stem wood	4.560	0.094	119	0.54
Stem bark	0.999	0.021	323	0.32
Litter	-0.414	-0.009	397	-0.16
Net:	20.400	0.420		4.85
Belowground				
Fine (<2 mm) roots	2.220	0.046	6450	14.30
Woody roots	7.390	0.152	3050	22.60
Net:	9.610	0.198		36.90
<b>Wet Meadow Herbs</b>				
Aboveground				
Foliage	3.530	0.122	922	3.26
Litter	-3.530	-0.122	922	-3.26
Belowground				
	28.500	0.983	7640	217.00
<b>Grand total</b>				<b>12.100</b>

from root surfaces prior to elemental analysis. Soil contamination is substantiated by Si levels in roots averaging 1.4% versus  $2000 \mu\text{g}\cdot\text{g}^{-1}$  in aboveground tissues. Wet meadow foliage had higher Al concentrations than foliage of other groups, resulting from the inclusion of Al hyperaccumulating species. However, the largest pool was found to exist in Pinus, due to its overwhelming biomass.

Most of the Al accumulation in vegetation occurred in meadow roots. Salix roots also showed high Al accumulation. Positive, but much lower rates of Al accumulation occurred in aboveground Salix and aboveground and belowground Pinus tissues. Since they are based on biomass productivity estimates and are thus subjected to the same errors as discussed above, the net accumulation of Al in the vegetation may be an overestimate of actual Al flux. The turnover of biological Al was rapid, resulting in a net flux of  $12 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$  out of  $40 \text{ kg}\cdot\text{ha}^{-1}$  total biomass-Al.

Free-Al<sup>3+</sup> in the soil solution is controlled by at least two weathering/release reactions (Lund et al. 1989). One reaction is quite rapid, accounting for at least 90% of acid neutralization in laboratory studies. In this reaction Al<sup>3+</sup> is released in a ratio of 3 moles H<sup>+</sup> per mole of Al<sup>3+</sup> (Figure 7). Solubility calculations indicate that the mineral involved is probably gibbsite (Lund et al. 1989). This mineral has not been identified in all soils in the watershed. One explanation is that the source of the Al<sup>3+</sup> may be Al(OH)<sub>3</sub> (amorph.) trapped in hydroxyinterlayered vermiculite, a clay mineral which is ubiquitous in ELW soils. Another explanation is that at sufficiently acid pH, Al<sup>3+</sup> associated with organic matter in soils will behave similarly to Al(OH)<sub>3</sub> (amorph.). Calculations indicate that this reaction has the potential for consumption of acidity on the order of 130 mEq for each square meter of soil

to a depth of 10 cm ( $m^2$  - 10 cm). Measurements of  $Al(OH)_3$  (amorph.) in soils found that this is the largest Al-pool in each community (Table II).

The second weathering reaction involves the decomposition of minerals derived from granite or granodiorite bedrock including feldspars, hornblende, and biotite. Plagioclase, a type of feldspar, has been identified as the mineral most important in this weathering reaction. While base cations are released in this reaction,  $Al^{3+}$  and  $Si^{4+}$ , are also released and in part recombine to form kaolinite (Lund et al. 1989). The formation of kaolinite and under certain conditions gibbsite, makes Al a conservative element in ELW soils.

The volume of outflow water from the watershed was measured to be 1127000, 668000, and  $2573000 \text{ m}^3 \cdot \text{yr}^{-1}$  during water years 1984, 1985, and 1986 (October 1983 through September, 1986), respectively. Unfiltered samples varied in Al concentration from 0.3 to  $2.7 \mu\text{M}$  in inflow water. Annual Al inflow was estimated to be  $41 \text{ kg} \cdot \text{yr}^{-1}$ , and represents the total annual loss of Al from the watershed. On a whole-watershed basis, Al efflux is  $0.3 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ ; compared to the soil Al pool of  $2600 \text{ kg} \cdot \text{ha}^{-1}$ , Al is conservative in the watershed.

#### Aluminum Phytotoxicity

The A. magnifica seedlings exhibited several pH-response zones in the presence of low ( $0.01 \mu\text{M}$ ) total Al which is within the range of normal background contamination (Figure 4). As pH decreased from 6.2 to 4.8, the RGR tended to increase. Calculations of free  $Fe^{3+}$  and  $Cu^{2+}$  indicate they are each about 10 times more abundant in the pH 4.8 than 6.2 solutions, and may be involved in the RGR increase. The increased availability of these ions is the result of their release from EDTA complexes in the nutrient solutions. Between

pH 4.8 and 4.0 RGR remained constant or decreased slightly. As pH dropped from 4.0 to 3.0 RGR increased rapidly; this apparently is a short-term response which never stabilized, at least under our experimental conditions. Below pH 3.0, RGR irreversibly declined to 0.

Earlier investigators have reported that in low pH environments, root cell walls lose their integrity and expand elastically (Pope 1977; Rayle and Cleland 1970). Currently we have insufficient evidence to conclude whether the Abies root is responding to changes in nutrient availability or a pH-induced alteration of cell wall elasticity. Monitoring  $O_2$  consumption and/or  $CO_2$  production as the nutrient solution passes the root may indicate how metabolic processes are affected by the pH shift.

In the presence of 10 mM Al, the response to decreasing pH fairly well traced that of the low Al solution (Figure 5). The major difference is that the increasing RGR as pH declined from 6.2 to 4.8 was suppressed in the presence of high Al. However, the rapid root expansion and mortality below pH 4.0 observed in low Al solutions also occurred in the presence of high Al. The root expansion is presumably due to a pH-induced change in root extensibility as discussed above, and not a response to Al.

Growth rate has been plotted in solutions of constant pH and varying  $Al^{3+}$  (Figure 6). Although the toxic threshold is yet to be established, a moderate decline in RGR with increasing free  $Al^{3+}$  is discernible.

Soils in the Typic Cryorthod map unit (Pinus community) have a pH ranging from 4.0 at the surface to 5.5 at 69 cm depth (Huntington and Akeson 1987). The dose-response results suggest that these values may be within the pH tolerance range of the conifers. However, in this pH range  $Al^{3+}$  may be present in sufficient quantities to affect growth (Figures 6 and 7). Dissolved  $Al^{3+}$

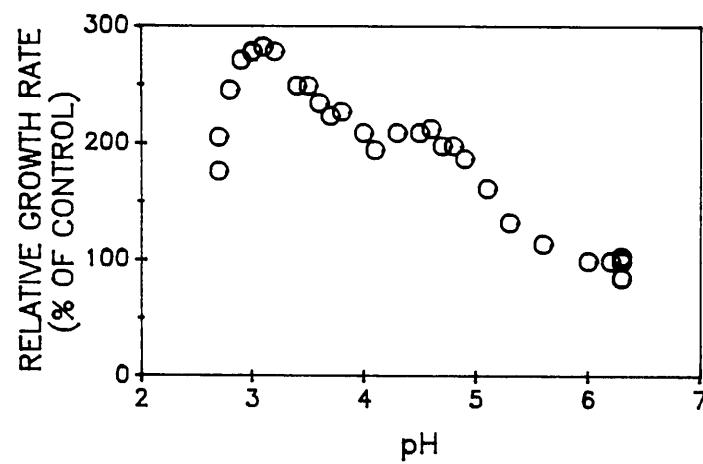


Figure 4. Response of *A. magnifica* roots to pH of nutrient solution. Nutrient solution contained 0.01 M total Al.

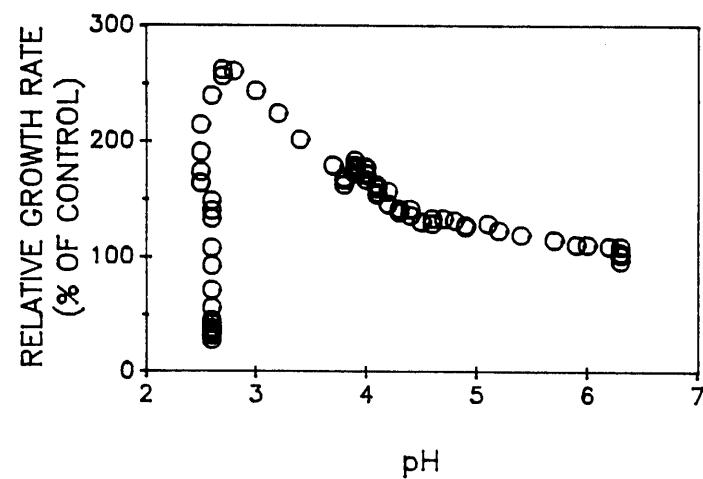


Figure 5. Response of *A. magnifica* roots to pH of nutrient solution. Nutrient solution contained 10 mM total Al.

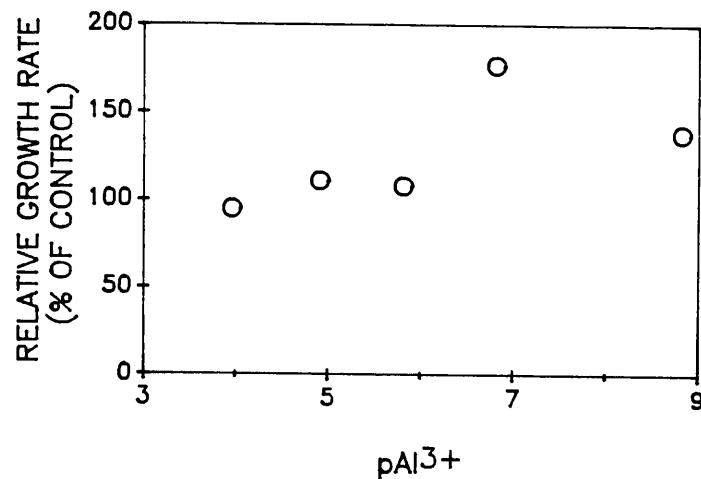


Figure 6. Response of *A. magnifica* roots to  $\text{Al}^{3+}$  in nutrient solutions at constant pH of 5.0.

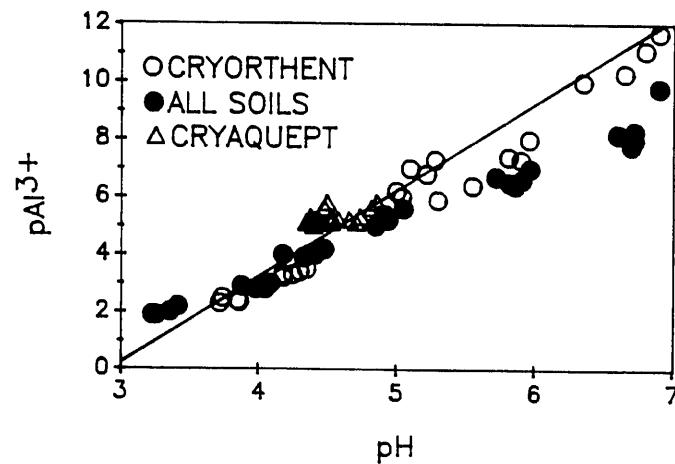


Figure 7. Solubility of Al in two Emerald Lake watershed soils.

concentrations on the order of 1  $\mu\text{M}$  in stream water indicate a level of availability of  $\text{Al}^{3+}$  in soil water.

Soils in the Lithic Cryumbrepts map unit (Salix community) have a pH of 5.2 throughout the depth of the profile, and the Cryumbrept map unit (wet meadow community) range in pH from 4.5 at the surface to 5.5 at 150 cm (Huntington and Akeson 1987). Although dose-response data are unavailable for these communities, the higher pH values suggest that they may be less at risk to Al or pH induced toxicities than the conifers.

#### SUMMARY

Aluminum is released into the soil primarily by the weathering of gibbsite and hydroxyinterlayer vermiculite in acid soils. Some of the  $\text{Al}^{3+}$  is absorbed by vegetation, where it is stored until returned to the soil through litter decomposition. Although large standing pools of biomass-Al were measured in roots, much of this may have been superficially adsorbed. The Pinus, Salix, and wet meadow communities appeared to be rapidly aggrading and accumulating Al, but inaccuracies of litter production and root turnover rate estimations may have skewed results. Forty-one  $\text{kg}\cdot\text{yr}^{-1}$  of Al is lost from the watershed.

Although there is no evidence indicating that soil acidity itself is adversely affecting vegetation, there may be a secondary Al-availability effect. Laboratory experiments suggest that growth rates of conifer roots may be suppressed in the presence of  $\text{Al}^{3+}$  levels similar to those measured in Emerald Lake watershed soils.

## REFERENCES

- Alexander, G. V. and L. T. McAnulty. 1981. Multielement analysis of plant-related tissues and fluids by optical emission spectrometry, J. Plant Nutr. 3:51-59.
- California Air Resources Board. 1988a. Fifth Annual Report to the Governor and the Legislature on the Air Resources Board's Acid Deposition Research and Monitoring Program. Sacramento, CA.
- California Air Resources Board. 1988b. The Health and Welfare Effects of Acid Deposition in California, An Assessment. Sacramento, CA.
- Chaney, R. L. 1988. Plants can utilize iron from Fe-N, N'-di'(2-hydroxybenzoyl)-ethylenediamine-N,N'-diacetic acid, a ferric chelate with  $10^6$  greater formation constant than Fe-EDDHA," J. Plant Nutr. 11:1033-1050.
- Dozier, J., J. M. Melack, D. Marks, K. Elder, R. Kattelmann, M. Williams. 1987. Snow Deposition, Melt, Runoff, and Chemistry in a Small Alpine Watershed, Emerald Lake Basin, Sequoia National Park. Final Report, Contract A3-106-32, California Air Resources Board, Sacramento, CA.
- Fogel, R. 1985. Roots as primary producers in below-ground ecosystems, IN: A. H. Fitter (ed.), Ecological Interactions in Soil. Blackwell Scientific Publications, Oxford, pp. 27-37.
- Gholz, H. L., C. C. Grier, A. G. Campbell and A. T. Brown. 1979. Equations for Estimating Biomass and Leaf Area of Plants in the Pacific Northwest. For. Res. Lab., Oreg. State Univ., Corvallis, Ore. Res. Pap. 41.
- Hodges, S. C. 1987. Aluminum speciation: a comparison of five methods." Soil Sci. Soc. Am. J. 51:57-64.

- Huntington, G. L. and M. A. Akeson. 1987. Soil Resource Inventory of Sequoia National Park, Central Part, California. Dept. of Land, Air, and Water Resources, Univ. of Calif., Davis.
- Hutchinson, T. C. and M. Havas. 1980. Effects of acid precipitation on terrestrial ecosystems, Plenum Press, N.Y., pp. 363-374.
- Ingestad, T. 1962. Macro Element Nutrition of Pine, Spruce, and Birch Seedlings in Nutrient Solutions, Meddelanden Fran Staten Skogsforskning-institut, Stockholm.
- Lund, L. J., A. D. Brown, and M. A. Lueking. 1989. Integrated Soil Processes Studies at Emerald Lake Watershed, Final Report, Contract A5-204-32, California Air Resources Board, Sacramento, CA.
- Melack, J. M., S. D. Cooper, R. W. Holmes, J. O. Sickman, K. Kratz, P. Hopkins, H. Hardenbergh, M. Thieme and L. Meeker. 1987. Chemical and Biological Survey of Lakes and Streams Located in the Emerald Lake Watershed, Sequoia National Park, Final Report, Contract A3-096-32, California Air Resources Board, Sacramento, CA.
- Melack, J. M., S. Cooper, T. Jenkins, L. Barmuta, S. Hamilton, K. Kratz, J. Sickman and C. Soiseth. 1989. Chemical and Biological Characteristics of Emerald Lake and the Streams in its Watershed, and the Responses of the Lake and Streams to Acidic Deposition, Final Report, Contract A6-184-32, California Air Resources Board, Sacramento, CA.
- Miller, P. R. (Tech. coord.). 1980. Proceedings of a Symposium on Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems, USDA Forest Service Gen. Tech. Report PSW-43.
- Mudd, J. B., and T. T. Kozlowski. 1975. Responses of Plants to Air Pollution. Academic Press, N.Y.

- Pavan, M. A., and F. T. Bingham. 1982. Toxicity of aluminum to coffee seedlings grown in nutrient solution, Soil Sci. Soc. Am. J. 46:933-997..
- Pearson, J. A., T. J. Fahey and D. H. Knight. 1984. Biomass and leaf area in contrasting lodgepole pine forests. Can. J. For. Res. 14:259-265.
- Pope, D. G. 1977. Separation of indol-3ylacetic acid-induced growth from acid-induced growth in Avena coleoptiles, Ann. Bot. 41:1069-1071.
- Rayle, D. L. and R. Cleland. 1970. Enhancement of wall loosening and elongation by acid solutions," Plant Physiol. 46:250-253.
- Smith, W. H. 1981. Air Pollution and Forests. Springer-Verlag, N.Y.
- Stark, N. 1972. Nutrient cycling pathways and litter fungi, Bioscience 22:355-360.
- Ulrich, B. 1983. A concept of forest ecosystem stability and of acid deposition as a driving force for destabilization, In: B. Ulrich and J. Pankrath (eds.), Effects of Accumulation of Air Pollutants in Forest Ecosystems. D. Reidel, Dodrecht, Holland, pp. 1-29.
- Westman, W. E. 1987. Aboveground biomass, surface area, and production relations of red fir (Abies magnifica) and white fir (A. concolor), Can. J. For. Res. 17:311-319.

## Red Fir Response to Rhizosphere Changes in pH and Aluminum

Conifers of California's Sierra Nevada grow on soils derived from acid parent materials (Huntington and Akeson 1987), which may additionally be impacted by acid precipitation (California Air Resources Board 1988a; California Air Resources Board 1988b). Acidity in the solution surrounding a root may directly affect root growth by altering the extensibility of cell walls (Rayle and Cleland 1970) or by interaction with the cell's metabolic machinery. This research was undertaken to establish the ranges of tolerance of Abies magnifica to pH, quantify the levels of damage response to specific pH levels, and identify possible mechanisms of toxicity.

### Materials and Methods

Root elongation was measured in a specially designed rhizotron (Figure 3). Complete nutrient solutions of a predetermined pH were pumped through a flow-cell in which a growing attached root was held. The root was backlit, and a microscope was focused on the root tip. A video camera monitored the image produced by the microscope, and a micro processor tracked the extension of the root tip, and delivered to a chart recorder a signal corresponding to the position of the root tip. (The image is simultaneously viewed on a monitor.) The growth of the root tip in real-time is displayed by the chart recorder allowing simple calculation of growth rate.

Solution passing the root was pumped from the flow-cell past a pH electrode with only a 15 second delay. The pH of the outflowing nutrient solution from the flow cell was recorded simultaneously on the chart with root extension, so that root extension measured at a given point in time could readily be

identified with the corresponding solution pH.

The experimental plants were three-year old Abies magnifica seedlings, which had been cultured in a potting mix in 20 cm conical containers. The day before a subject plant was to be studied, the bottom 5 cm of the plastic container was carefully removed and the potting mix gently washed from the exposed root mat (mostly root tips at this stage of growth). The exposed roots were then held in an aerated, 1/10 strength Ingestad nutrient solution until the next morning. An actively growing root identified by its fresh white coloration and turgid condition was selected for study and inserted into the rhizotron. The remaining roots were left intact still attached to the seedling, and wrapped in parafilm to prevent desiccation. The subject root was then placed in the flow-cell, and a fluorescent light was suspended above the whole plant to maintain a light intensity of  $250 \mu\text{Mm}^{-2}\text{s}^{-1}$ .

The nutrient solution used for all experiments and for the overnight root acclimation contained  $0.2 \text{ mM Ca}^{2+}$ ,  $0.25 \text{ mM K}^+$ ,  $0.15 \text{ mM Mg}^{+2}$ ,  $0.2 \text{ mM NH}_4\text{NO}_3$ ,  $0.15 \text{ mM SO}_4^{2-}$ ,  $0.1 \text{ mM PO}_4^{+3}$ ,  $9 \mu\text{M Fe-EDTA}$ ,  $5 \mu\text{M BO}_3^{3+}$ ,  $0.9 \mu\text{M Mn}^{2+}$ ,  $0.08 \mu\text{M Zn}^{2+}$ ,  $0.03 \mu\text{M Cu}^{2+}$ , and  $0.01 \mu\text{M MoO}_4^{2-}$  (Ingestad 1962), and was initially adjusted to pH 6.2 with KOH. Aluminum ( $0.01 \mu\text{M}$ ) was added as a background for Al dose-response experiments.

To estimate the concentration of free  $\text{Al}^{3+}$  (the most probable plant-available Al form (Pavan and Bingham 1982)) in the nutrient solutions, the chemical equilibria model GEOCHEM was applied (Chaney 1988). Using the GEOCHEM model a curve was developed for the pH range of 2.5 to 6.5 in 0.1 pH unit increments which produced the  $\text{pAl}^{3+}$  (the negative log of the solution  $\text{Al}^{3+}$  concentration) for our experimental conditions.

When root growth had stabilized (usually within 1 h, previous studies of root growth have also indicated a period of stabilization after handling of

roots (Cramer et al. 1988)), a control growth rate was determined. The control growth rate is defined as the average growth rate for a 30 minute period after stabilization of that root. Subsequent measurements of growth rate were expressed as a fraction of the control, and referred to as the relative growth rate (RGR).

For detailed data analysis, points at 5 min. intervals were selected from the continuous curve. Measurements were smoothed by averaging each successive set of 7 points. Relative growth rate was plotted against solution pH to establish a pH response curve.

Experiment 1. Since many of the experiments were by necessity conducted over a course of several hours, there was a possibility that part of the observed responses could have been the result of environment in the rhizotron. To investigate possible rhizotron effects on root growth, experiments were conducted for long periods of time (5.5 hr) at a constant pH (6.2). These studies showed that once the roots stabilized their growth rate were constant ( $4 \mu\text{m} \cdot \text{min}^{-1}$ ) for the length of these studies.

Experiment 2. To establish the general zones of a pH-response curve, roots were placed in the flow-cell and the pH of the nutrient solution was gradually lowered. After the control growth rate for a particular root had been established, the pH of the flowing nutrient solution was gradually changed. This was achieved by using a secondary nutrient solution of similar composition to the primary, but adjusted to a different pH, 2.5, which was slowly pumped into the primary nutrient solution with a constant volume pump. The primary nutrient solution was continuously mixed so that it rapidly reached equilibrium with the incoming nutrient solution. The primary nutrient solution was then

pumped to the flow cell using another constant volume pump. This experiment was replicated five times, and the course of lowering the pH of the solution passing the root from 6.2 to 2.5 ranged from 2 to 5 hours to allow evaluation of root response time.

Experiment 3. Having established the general shape of the curve from Experiment 2, the response to the acid pH zone was examined in more detail. A root was placed in the rhizotron with the nutrient solution adjusted to pH 6.2, and monitored until a steady growth rate was established. The solution was maintained at this pH for an additional 80 minutes. Then a nutrient solution of a lower pH (3.8) was pumped through the flow-cell, immediately lowering the pH to which the root was exposed. Growth rate was monitored for an additional 270 minutes.

Experiment 4. The pH-response curve described in Experiment 2 was conducted in the presence of high ( $10 \text{ mM}$ ) Al. At pH 6.2 the concentration of free  $\text{Al}^{3+}$  in the solution was  $0.005 \mu\text{M}$ . This level is within background ranges of Al, and so roots in this solution adequately serve as controls for the curve. The highest  $\text{Al}^{3+}$  levels were attained below pH 4.5, at which concentrations reached  $3000 \mu\text{M}$ .

Experiment 5. In this experiment the response of roots to varying levels of Al in constant pH (5.0) was tested. This pH was chosen from the results of Experiment 2, which showed it to be satisfactory for unimpaired root growth, and also because it was sufficiently acid to release relatively high levels of  $\text{Al}^{3+}$ . Total Al ranged from 0.01 to  $10000 \mu\text{M}$ . In control solutions of pH 6.2 free  $\text{Al}^{3+}$  ranged from  $10^{-6}$  to  $0.005 \mu\text{M}$ , and in the pH 5.0 solutions it

ranged from 0.001 to 100  $\mu\text{M}$ . Roots were placed in the rhizotron, exposed to the control nutrient solution, and monitored until a stable growth rate was achieved. Growth rate in the control solution was then recorded for 30 min., then the root was exposed to an equal total Al level, but at pH 5.0. After growth rate had stabilized under these new conditions, it was recorded for 30 minutes. Growth rates for comparison purposes were normalized to RGR as described above.

### Results and Discussion

Experiment 1. The results from Experiment 1 (Figure 8) show that the RGR remains stable in the rhizotron during 5.5 hours of monitoring. Any changes measured in RGR using similarly prepared plants may be assumed to be in response to applied treatments.

Experiment 2. The five pH response curves developed from Experiment 2 are presented in Figure 9. In general, four response zones are discernible. As pH decreased from 6.2 to 4.8, RGR tended to increase. Calculations of free  $\text{Fe}^{+3}$  and  $\text{Cu}^{+2}$  in the nutrient solution using GEOCHEM indicate that they are each about 10 times more abundant at pH 4.8 than 6.2. Thus the response to pH in this range may be the result of an induced change resulting from a change in  $\text{Fe}^{+3}$  and  $\text{Cu}^{+2}$  availability. The increase in concentration of  $\text{Fe}^{+3}$  and  $\text{Cu}^{+2}$  apparently is the result of changes in the equilibrium with EDTA in the nutrient solutions. Similar changes could occur with pH and natural chelates in soil systems. Between pH 4.8 and 4.0 RGR remained constant or decreased slightly. As pH dropped from 4.0 to 3.0 RGR apparently increased rapidly. Below pH 3.0, RGR irreversibly declined to 0.

Some of the variability of inflection points among the curves may be explained by the rates of pH change. The ranges of rates of pH drop averaged 0.6 to 1.6 pH units per hour in the experiments presented in Figures 9d and 9e, respectively. This variability suggests a lag between the time the solution of a given pH passes the root and the plants response to it. This aspect is further developed in Experiment 3.

Earlier investigators have reported that in low pH conditions, root cell walls lose their integrity and expand elastically (Rayle and Cleland 1970, Pope 1977). Currently we have insufficient evidence to conclude whether the Abies root is responding to changes in nutrient availability or a pH-induced alteration of cell wall elasticity. It would be desirable to monitor  $O_2$  consumption and/or  $CO_2$  production as the nutrient solution passes the root to determine how and when metabolic processes are affected by a pH shift at the surface of the root.

Experiment 3. A root established in the control nutrient solution, then suddenly exposed to a pH 3.8 solution, exhibited two response phases (Figure 10). The first, an immediate five-fold increase of RGR, occurred presumably due to a change in cell wall elasticity. In the second phase, RGR diminished, eventually to 0 and was presumably dead, for the root did not resume growth when returned to a complete nutrient solution at pH 6.2. This seems to indicate that the response curves developed from Experiment 2 reflect a complex of at least two affected processes: root elasticity and cellular metabolism.

Experiment 4. In the presence of 10 mM Al, the response to decreasing pH fairly well traced that of the low Al solution (Figure 11). The major difference is that the increasing RGR as pH declined from 6.2 to 4.8 was suppressed in the

presence of high Al. However, the rapid root expansion and mortality below pH 4.0 observed in low Al solutions also occurred in the presence of high Al. The root expansion is presumably due to a pH-induced change in root extensibility as discussed with respect to Experiment 2, and not a response to Al.

Experiment 5. At pH 5.0 and low ( $0.01 \mu M$ ) total Al, root elongation was approximately 50% more rapid than at pH 6.2 (Figure 12). This may result from a change in membrane extensibility and/or physiological responses at the lower pH, as discussed in Experiment 2. At pH 5.0 and high ( $10000 \mu M$ ) total Al, root elongation rate was approximately equal to that of the root in the pH 6.2 solution of high total Al. Between these two extremes a gradual decline in growth rate is discernible. Two possible reasons for the decline may be a suppression by Al of metabolic processes, or interference by  $Al^{3+}$  with the proton effect on membrane extensibility.

### Literature Cited

- California Air Resources Board. 1988a. Fifth annual report to the Governor and the Legislature on the Air Resources Board's acid Deposition Research and Monitoring Program. Sacramento, California.
- California Air Resources Board. 1988b. The health and welfare effects of acid deposition in California, an assessment. Sacramento, California.
- Chaney, R. L. 1988. Plants can utilize iron from Fe-N,N'-di'(2-hydroxybenzoyl)-ethylenediamine-N,N'diacetic acid, a ferric chelate with  $10^6$  greater formation constant than Fe-EDDHA. J. Plant Nutr. 11:1033-1050.
- Cramer, G. R., E. E. Epstein, and A. Lauchli. 1988. Kinetics of root elongation of maize in response to short-term exposure to NaCl and elevated calcium concentration. J. Exp. Bot. 39:1513-1522.
- Huntington, G. L., and M. A. Akeson. 1987. Soil resource inventory of Sequoia National Park, Central Part, California. Dept. of Land, Air, and Water Resources. Univ. of Calif., Davis.
- Ingestad, T. 1962. Macro element nutrition of pine, spruce, and birch seedlings in nutrient soutsions. Meddelanden Fran Staten Skogsforskninginstintut. Stockholm.
- Pope, D. G. 1977. Separation of indol-3ylacetic acid-induced growth from acid-induced growth in Avena coleoptiles. Ann. Bot. 41:1069-1071.
- Rayle, D. L., and R. Cleland. 1970. Enhancement of wall loosening and elongation by acid solutions. Plant Physiol. 46:250-253.

Figure 8. Growth rate of Abies magnifica root in rhizotron during 5.5 hour monitoring

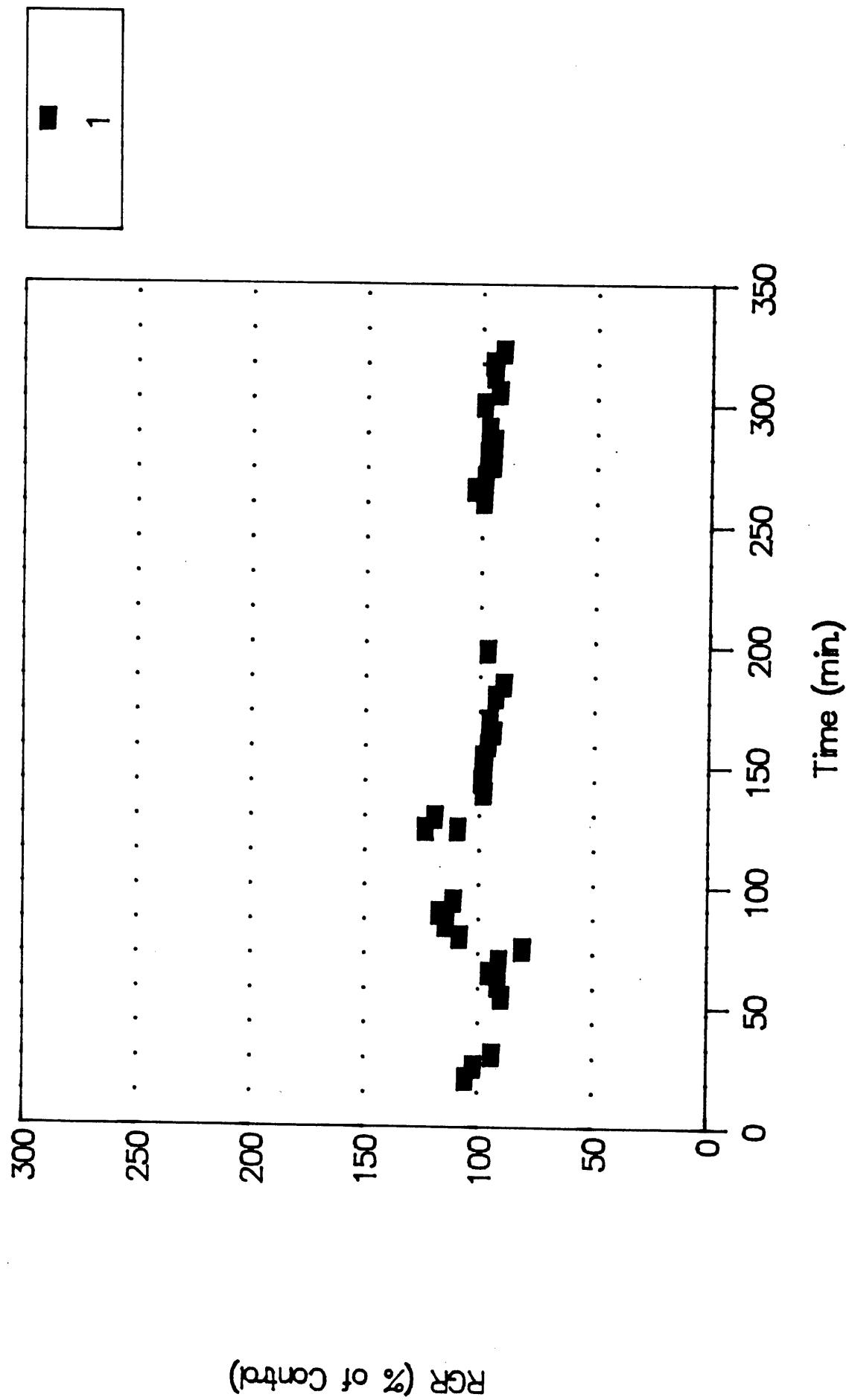
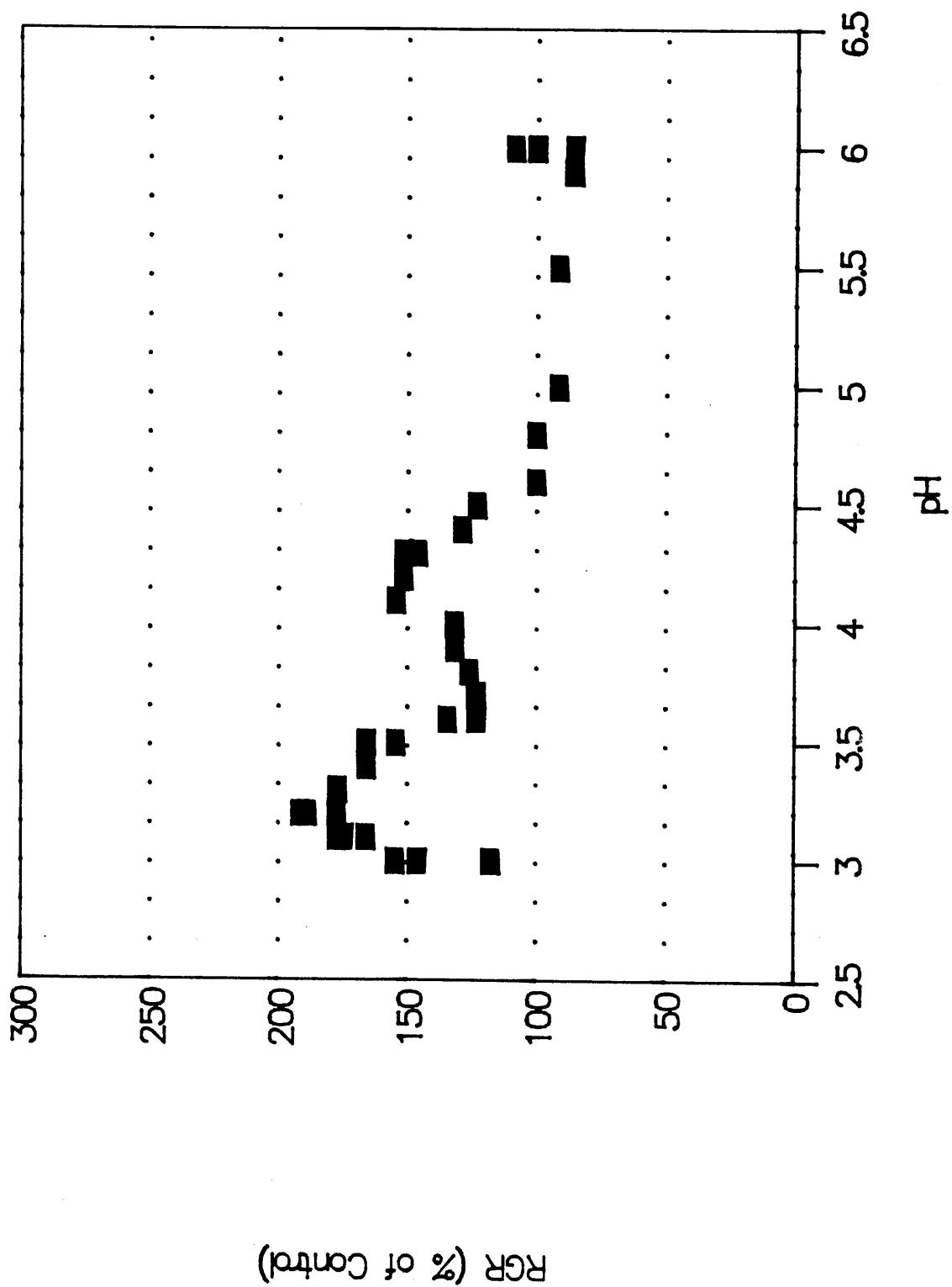


Figure 9a-e. Responses of Abies magnifica roots to gradual lowering of nutrient solution pH in the presence of background Al levels. Mean rates of pH change were 1.0, 0.7, 1.0, 0.6, and 1.6 pH units per hour for curves 9a through 9e, respectively



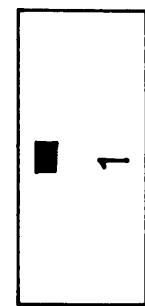


Figure 9 b

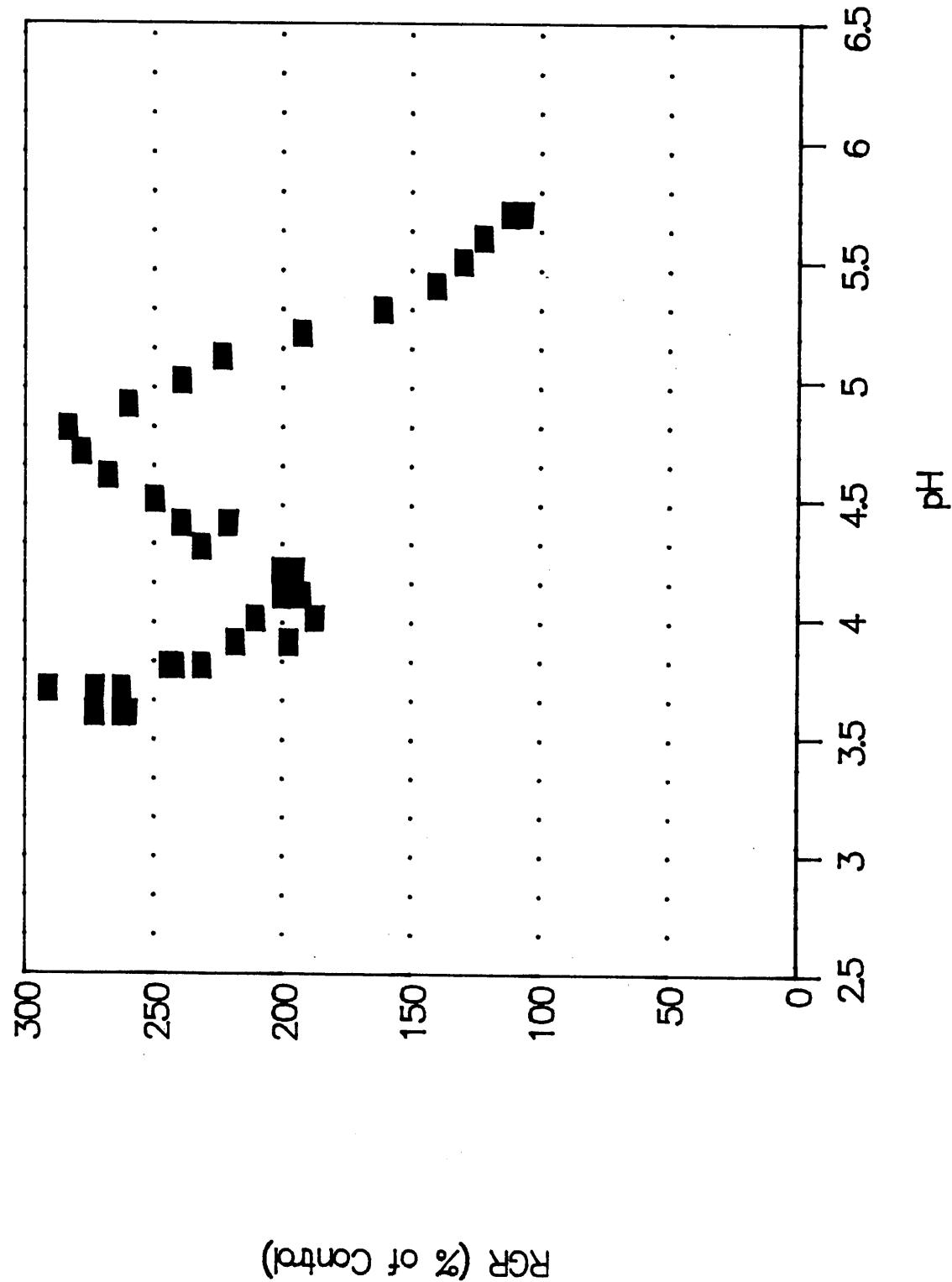


Figure 9c

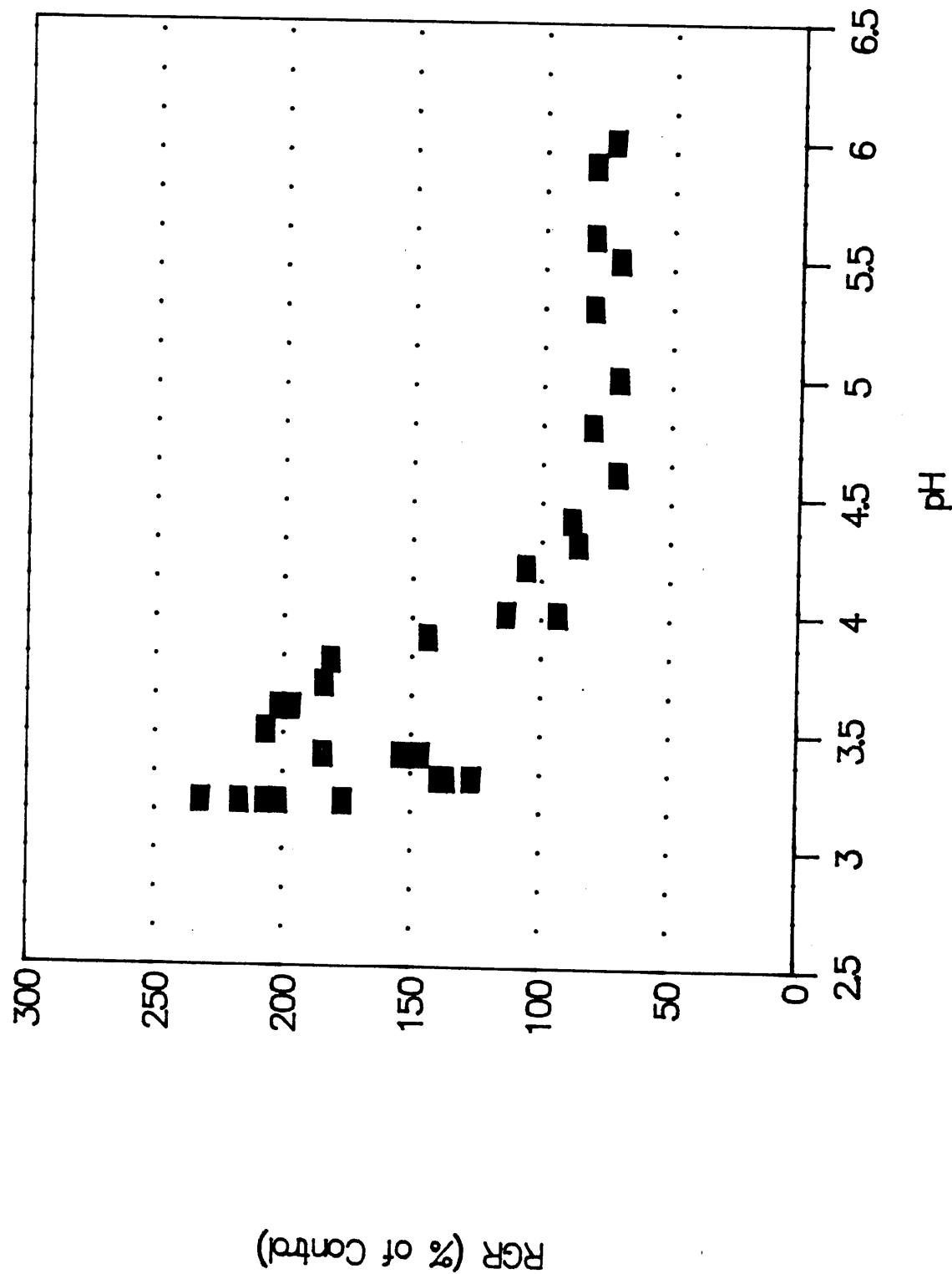


Figure 9d

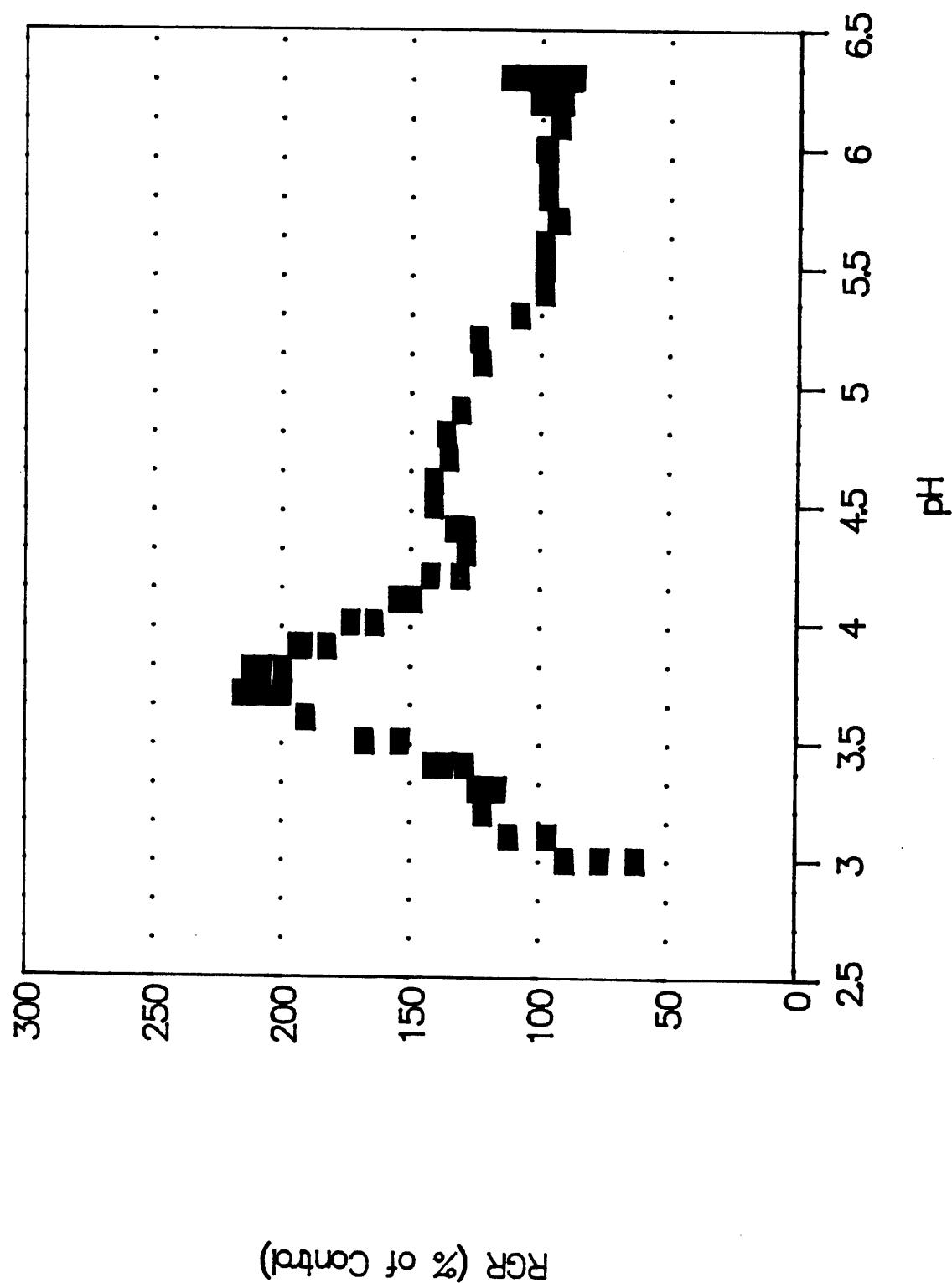


Figure 9e

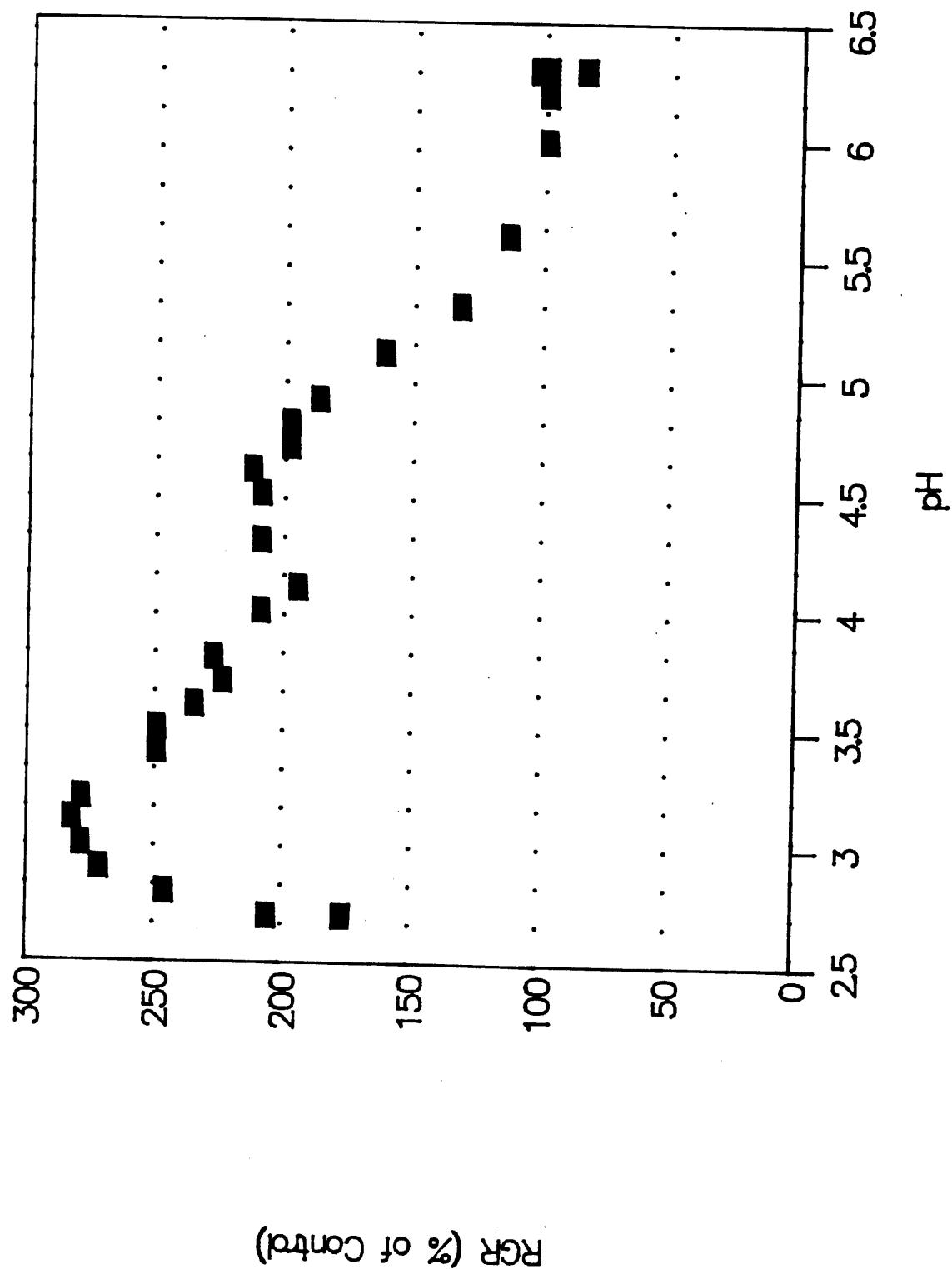


Figure 10. Response of Abies magnifica root to pH 3.8 nutrient solution. The times during which the root was exposed to solutions of either pH 6.2 or 3.8 are indicated near the top of the chart

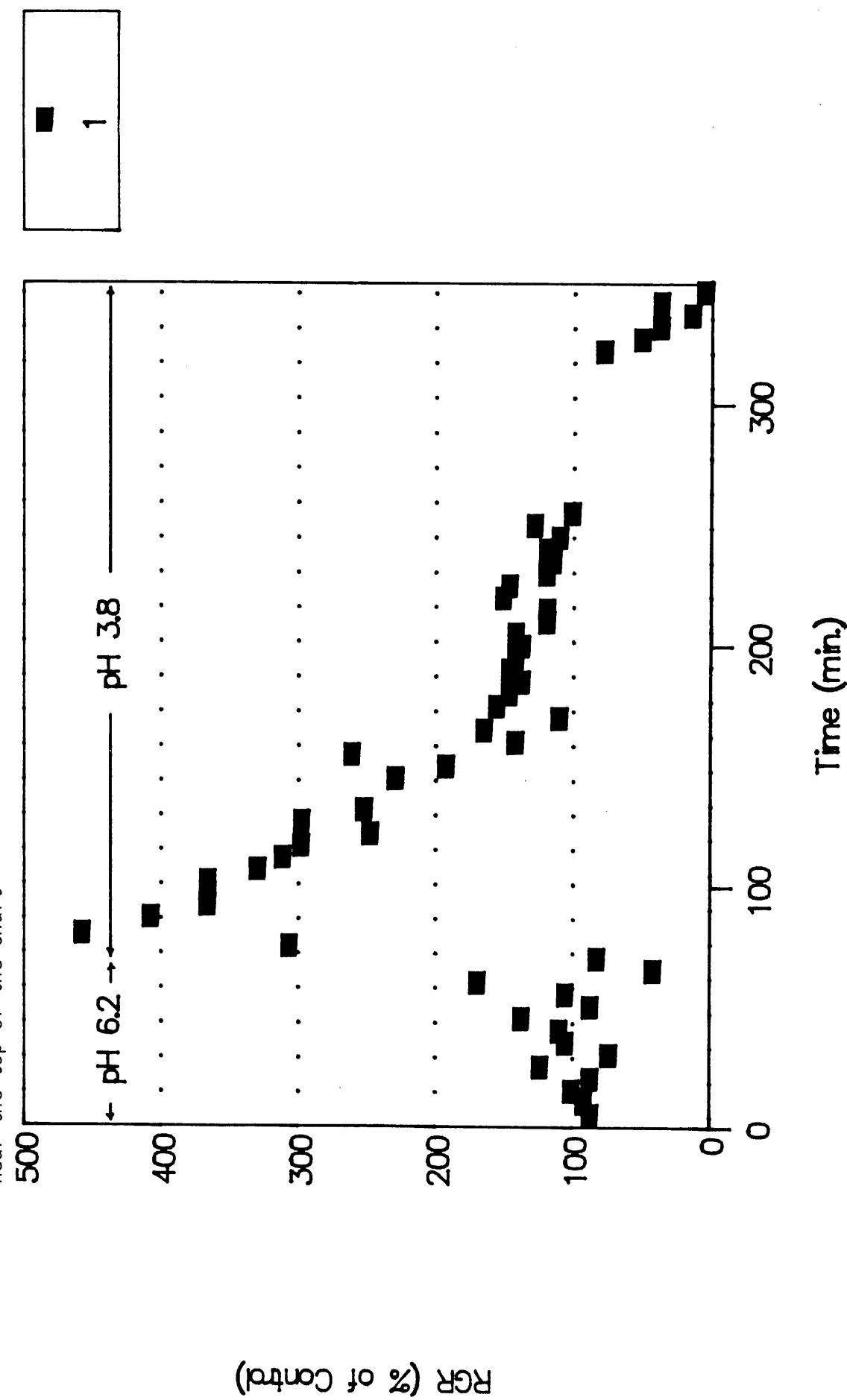
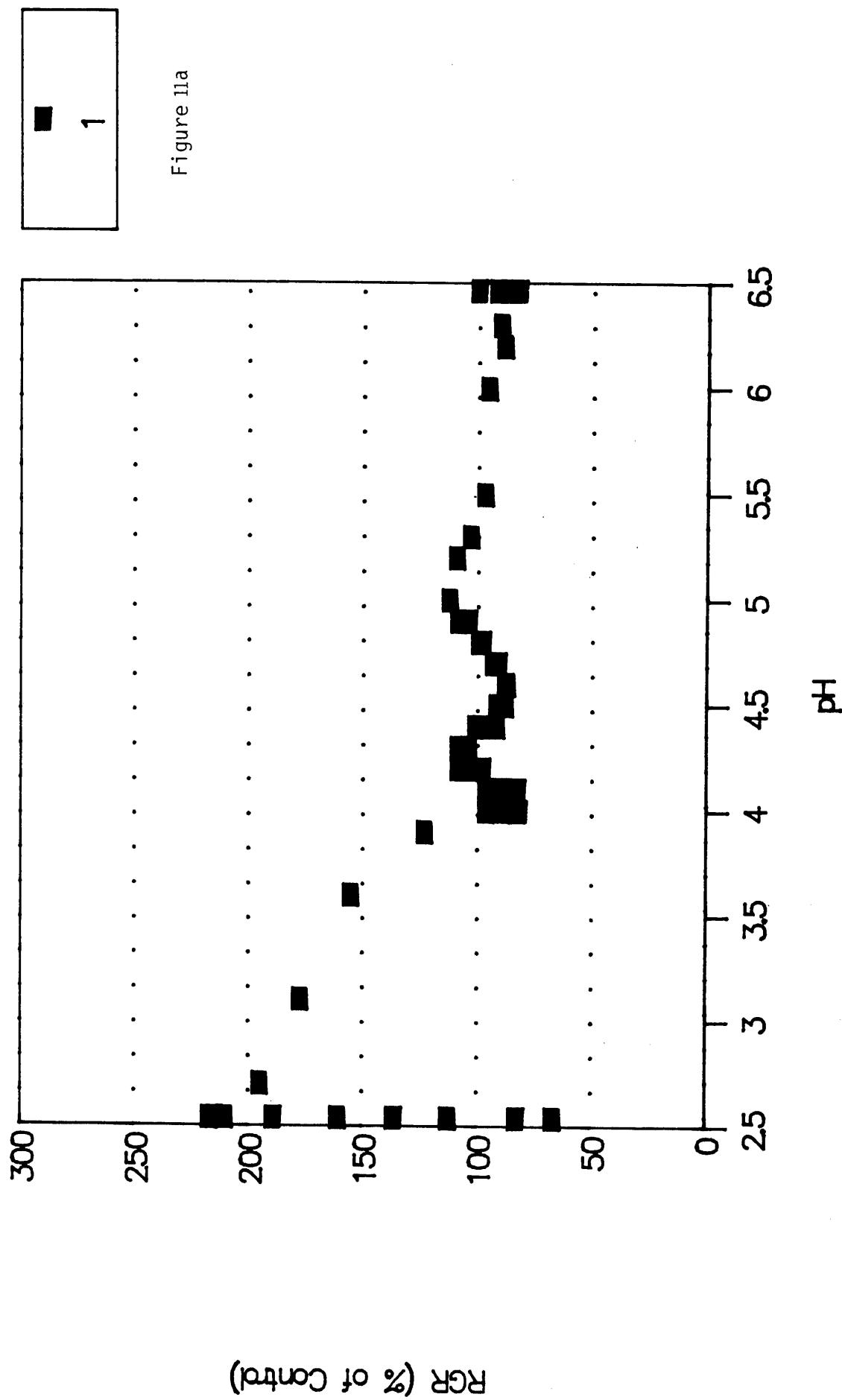


Figure 11a-b. Responses of Abies magnifica roots to gradual lowering of nutrient solution pH in the presence of 10 mM total Al. Average rates of pH change were 0.9 and 0.7 pH units per hour for curves a and b, respectively



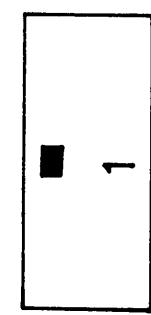
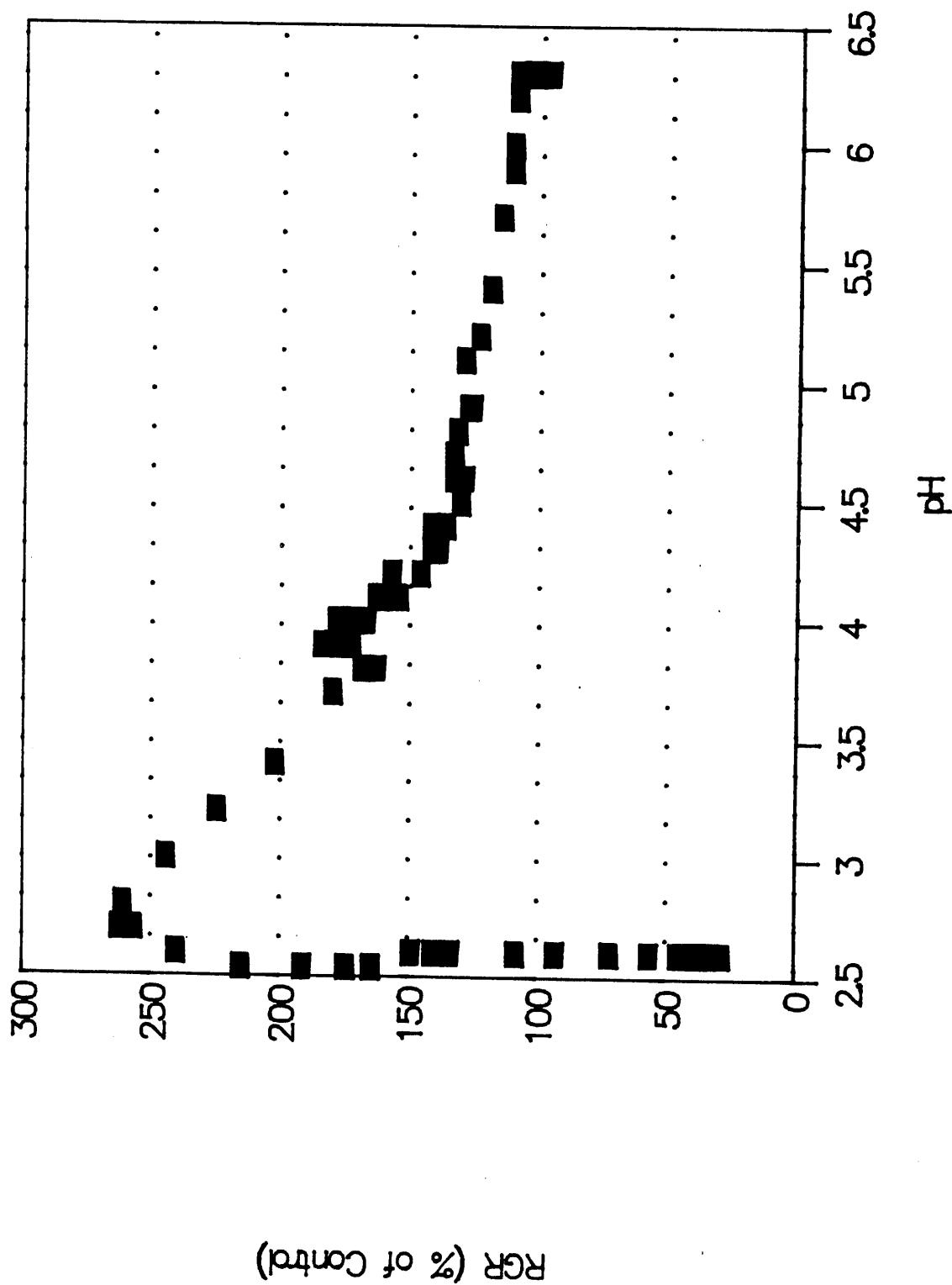


Figure 11 b



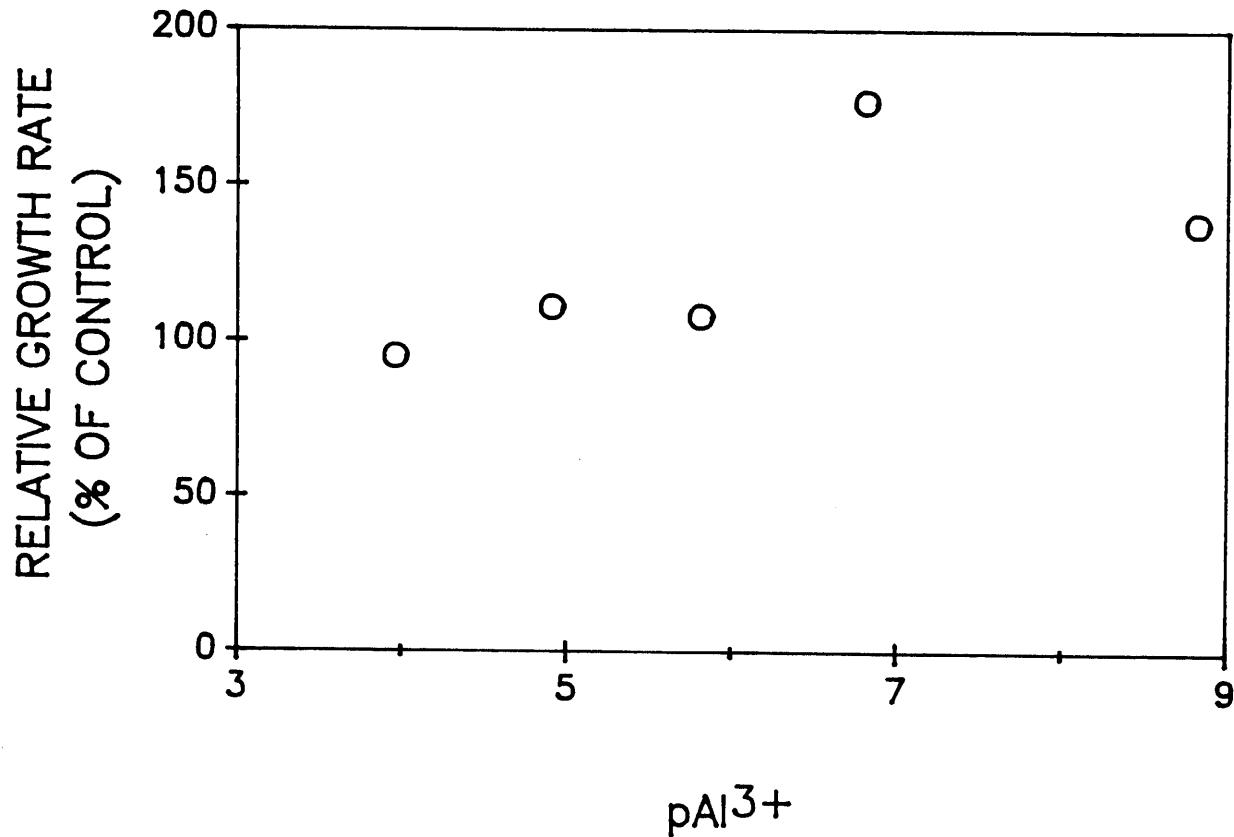


Figure 12. Response of Abies magnifica roots to  $\text{Al}^{3+}$  in nutrient solutions of constant pH 5.0

## Vegetation Units in the Emerald Lake Basin

The vegetation of Emerald Lake basin was divided into six association types by L. Norris (1984). These designations were revised and expanded by M. Neuman (1985) to include eight types. The present report describes the associations whose locations and relative areas are depicted on the vegetation map prepared in 1987. The eight associations determined in 1985 are retained, with some modifications and one addition. The colluvium association is described in greater detail, with quantification of plant cover and species richness.

Eight associations were described qualitatively based on 1987 field notes, the 1984 and 1985 botanical reports, and on the 1985 species list. The ninth association (colluvium) includes the relative abundance of common species and plant cover. Plant cover is also estimated for the fell field. Cover is inferred for the other associations by comparison to data obtained for the colluvium and fell field.

Twelve line transects were walked to determine the relative abundance of colluvium species. The transects followed arbitrary directions and were ten to fifteen paces long. The number of individuals intersecting an imaginary line drawn from toe to heel were counted. For creeping plants such as Primula suffrutescens and Cryptogramma acrostichoides, each basal rosette or stem was considered an individual. Selaginella watsonii grows in continuous mats along the margins of rocks. Each discrete patch was considered an individual.

Cover was determined for six ten-pace transects. The percent of the imaginary line covered by vegetation was estimated at 10% intervals from 10% to 100%, and at 5% intervals from 0 to 10%. Cover was estimated for each pace, then averaged over the transect. The standard deviation of the running mean was less than 5% for six transects. In the fell field, cover is quite low and only a few transects were walked.

## Association Descriptions

### Colluvium

The colluvium association occurs in the fault trace on the southwestern boundary of the watershed, and in two smaller regions to the south, where large boulders give way to smaller granitic rocks 0.3 - 1 m long along the major axis. The substrate is steeply sloped with some soil development. Plant density is determined by rock distribution. The colluvium is vegetated almost entirely by small (20 cm) perennial herbs whose growth is limited to areas between the rocks. There are a few isolated Salix oreastera and Ribes cereum in the southern part of the lower quarter, and a stand of stunted (about 1 m tall) Pinus monticola on the northwest margin of the fault. A patch of Phyllodoce breweri is adjacent to and south of the Pinus monticola stand.

The species which dominate the colluvium both in number and density are Senecio fremontii, Eriogonum incanum, Carex lanuginosa (or C. sartwelliana), Phlox diffusa, Erysimum perenne, and a grass (Table 1). These six species occur in two-thirds of the transects and comprise two-thirds of the individuals counted. Senecio fremontii is particularly important, accounting for almost 20% of the vegetation. An additional 11 species make up the remaining third. Cryptogramma acrostichoides and Selaginella watsonii, both of which grow along the margins of the larger rocks, are widely dispersed but occur in low densities, accounting for 4% and 2% of the cover, respectively.

The plant cover is about 25% (Table 2). The standard deviation is about 22% when each pace is considered separately, but only 3% when the six transects are compared. This reflects the local heterogeneity (due to the nature of the substrate) as well as the overall uniformity of cover. The Phyllodoce breweri stand is most dense, covering 30% of the substrate.

### Fell Field

The fell field is found on the plateau below Alta Peak, overlooking Pear Lake. It is geomorphologically similar to the colluvium, but it is flat and has a northerly aspect. Rocks are slightly smaller and are much farther apart, exposing bare soil. Unlike the colluvium, where plants have colonized all bare soil, the fell field is very sparsely vegetated. Distribution is patchy; nowhere is the density more than 10%. Average density is about 5%, with much of the area completely bare. Six species occur here: Chaenactis alpigenus, Carex helleri, Ranunculus eschscholtzii, Arenaria nuttallii ssp gracilis, Eriogonum incanum, and Saxifraga tolmiei. The first two are unique to this type.

### Xeric Meadow

Xeric meadows (abbreviated GHX, for "graminoids and herbs, xeric") occupy the largest area in the basin. The largest single area of this type occurs on the plateau below the northeast ridge and boundary of the basin. There are also meadows northeast of the upper pond, adjacent to the Pinus monticola stand in the northernmost corner of the basin, and in the northeast fault, as well as on small areas on the southfacing slope wherever it is flat.

Density apparently varies with drainage. The areas below the ridge are most sparse, with about 20-25% cover. The meadows near the pond and in the fault may have 50% or more cover. The Phyllocladus breweri stand in the east fault is nearer 100%, but this stand covers a relatively small area. Some stands of Dicentra nevadensis, high on the east slope on loose sloping gravel, also approach 100% cover.

In 1984, 64 species were found in this association, and 69 were included in the 1985 species list. No attempt was made in 1987 to reclassify this association, nor to rank species for numerical abundance or relative density.

### Xeric Rock Crevices

Xeric rock crevices (abbreviated RCX) support dense populations of Penstemon newberryi, Holodiscus microphyllus var. microphyllus, Sedum obtusatum ssp. obtusatum, and Spiraea densiflora in narrow (up to 0.5 m) cracks in the granite faces of the east slope. Eriogonum nudum, Ivesia pygmaea, other herbs common to the xeric meadows, as well as xeric grasses and sedges also occur here, but are numerically eclipsed by the larger shrubs.

Where the cracks occur, cover is 100%. However, the cracks themselves probably cover no more than 5% of the granite faces, and perhaps less.

### Xeric Trees

There are several stands of conifers in the basin, but "xeric trees" (abbreviated TX) refers only to the Pinus monticola stands in the northernmost part of the basin. These stands are dense (trees less than 3 m apart), xeric, and have an understory of Chrysolepis sempervirens on dry, sandy slopes.

Some scattered Pinus monticola also occur in the flat, dry meadows below the eastern ridge. A few Pinus contorta are found in wet meadows in the main drainage close to the lake, and on the northern margin of the colluvium. None of these appear to influence the surrounding vegetation, and the understories are not unique. They do not represent unique vegetation types, but are part of dry meadow, wet meadow, and colluvium associations, respectively. Pinus balfouriana occurs only high on the southwest ridge, which was not visited in 1987.

The Chrysolepis sempervirens understory has 80-100% coverage. It interdigitates with Phyllocladus breweri on the lower slopes where this association merges with the dry meadow in the eastern fault trace. There are some regions of bare ground, but many appear to be trodden paths rather than natural features of distribution.

Sixteen herbs were found here in 1985. The shrubs (besides C. sempervirens and P. breweri) are Arctostaphylos nevadensis, Amelanchier pallida, Prunus emarginata, and Sorbus californica. I do not include Lonicera conjugialis in this association, since it is much more common on more mesic sites in rock cracks and rockpiles.

#### Wet Meadows

Wet meadows (also called "graminoids and herbs, mesic" GHM) occur in flat places where soil accumulates and remain wet most of the summer. The largest areas of wet meadow are high in the basin, adjacent to and above the small pond, where snowmelt keeps the soil saturated. Another important group of wet meadows lies on a bench running southwest from the largest Pinus monticola stand. Wet meadows also interdigitate with willow stands along the main drainage.

Our 1985 botanical report defines six subtypes. No attempt was made in 1987 to reevaluate these subtypes, nor to identify them on the vegetation map. Dominant species are identified in the 1985 botanical report. All wet meadows are dense turfs or stands with 100% cover.

#### Mesic Rock Crevices

Mesic rock crevices (RCM) contain essentially the same species as the wet meadows, in narrow (up to 0.5 m) cracks in the eastern granite face. These mesic crevices only occur where runoff is sufficient, such as below benches

supporting wet meadows. In the crevices, cover is 100%. However, the crevices themselves probably cover less than 5% of the rock faces.

### Mesic Shrubs

This association was defined in 1987. Mesic shrubs grow between boulders in slide areas where mesic conditions prevail. The boulders are 0.5 - 1.5 m along the major axis. Major species are Lonicera conjugialis, Lonicera involucrata, Sambucus microbotrys, Aquilegia formosa, A. pubescens, and Helenium bigelovii.

### Willows and Trees

The Willows and Trees association (called Shrubs, Willows, and Trees (SWT) in earlier reports) is dominated by Salix oreastera on deep, organic, hydric soil. It fills most of the main drainage and extends to several benches above the small upper pond. This association interdigitates with wet meadows wherever it occurs. Cover is 100%.

Table 4. Relative abundance of colluvium species.

	No. of Indiv.	Rel. density (%)	Rel. frequency (%)
<u>Senecio fremontii</u>	58(18)[8]	18	67
<u>Eriogonum incanum</u>	51(15)[8]	15	67
<u>Carex lanuginosa</u>	34(10)[7]	10	58
<u>C. sartwelliana</u>			
<u>Phlox diffusa</u>	24(7)[8]	7	67
<u>Erysimum perenne</u>	23(7)[7]	7	58
Grass	23(7)[7]	7	58
<u>Primula suffrutescens</u>	16(5)[3]	5	25
<u>Carex heteroneum?</u>	15(5)[3]	5	25
<u>Phyllodoce breweri</u>	15(5)[1]	5	8
<u>Cryptogramma acrostichoides</u>	14(4)[7]	4	58
Rosette herb (flowers in open panicle)	9(3)[2]	3	17
<u>Ivesia santolioides</u>	8(2)[2]	2	17
<u>Selaginella watsonii</u>	6(2)[5]	2	43
<u>Anenome occidentalis</u>	6(2)[3]	2	25
<u>Castilleja disticha</u>	6(2)[3]	2	25
Jointed grass	4(1)[1]	1	8
<u>Eriogonum nudum</u>	3(1)[1]	1	8
Grass with open panicle	3(1)[2]	1	17
<u>Aquilegia formosa</u> or <u>pubescens</u>	2(1)[1]	1	8

Table 5. Relative plant cover of the colluvium.

<u>Transect Number</u>	<u>Percent Cover by Pace</u>	<u>Mean Cover</u>
1	10, 05, 30, 20, 20, 40, 60, 20, 10, 0	22
2	40, 40, 30, 30, 20, 05, 50, 05, 0, 05	22
3	50, 30, 20, 0, 10, 0, 30, 30, 20, 30	22
4	10, 10, 30, 10, 10, 30, 20, 50, 60, 30	26
5	10, 60, 0, 10, 70, 0, 80, 30, 20, 30	31
6	0, 10, 20, 0, 40, 30, 100, 0, 05, 0	20

Table 6. Mean mapped area of major vegetation units within the Emerald Lake Basin and mean coverage of plant groups within these mapped units.

Community type	Community area (ha)	Mean Cover (%)
Willows and Trees	8.55	
Aboveground		
<u>Salix oreastera</u>		36 (see note 52)
Shrubs		10 (see note 52)
Live Herbs		7 (see note 52)
Mesic Shrubs	0.73	30
Mesic Rock Crevices	15.15	2
Wet Meadows	4.14	100
Aboveground		
Conifers	Censused individually	
Aboveground		
Xeric Rock Crevices	13.41	
Shrubs		1
Herbs		1
Dry Meadows	7.73	38
Fell Field	0.84	
Aboveground		
Live Herbs		2
Colluvium	3.44	2

## METHODS OF COMMUNITY AND WATERSHED NUTRIENT ANALYSES

The vegetation studies quantified standing biomass pools, productivity rates, vegetation mineral capitals, and vegetation mineral flux rates of the nine major vegetation groups in the watershed. Pools, capitals, and rates for the conifers were estimated for a whole-watershed basis. For the eight other groups, pools, capitals, and rates were estimated both for a whole-watershed basis and a community basis.

Biomass pools on a community basis were estimated as the product of the biomass and of that community type per unit area of that community type. Biomass pools on a whole-watershed basis were estimated as the product of the community biomass pool and the community area divided by the watershed area. Methods for estimating productivity on a community basis are described separately for each community. Productivity on a whole-watershed basis was estimated as the product of the community productivity and community area divided by the watershed area.

Unless otherwise noted, the following procedures were used to assay tissue for mineral contents. Nitrogen and phosphorus analyses were conducted by the University of Alaska using standard procedures for a Technican autoanalyzer system. Sulfur was analyzed using a LECO combustion system. All other elements were analyzed using optical emission spectroscopy at UCLA (Alexander and McAnulty, 1981).

### Conifers

Diameter at breast height of every tree in the basin was measured during the summer of 1985. Total aboveground biomass of the conifers was estimated from regressions on diameter at breast height (dbh) developed from Pinus

lambertiana (Gholz et al. 1979). Fine root (< 2 mm) and woody root (> 2 mm) biomasses were estimated as 6% and 20% of the total biomass (Pearson et al. 1984). Annual productivity was estimated as a percent of standing biomass using parameters developed for Sierran Abies species (Westman 1987).

Annual litter productivity rates were measured by researchers from the University of California, Riverside. The ash content of zeroth-year litter was assumed equal to needle ash weight. Litter residence time was estimated from the function:

$$y_t = y_0 \exp(-0.0943t) \quad (1)$$

Developed from Pinus jeffreyi (Stark 1972), solving for t (years) with  $y_t$  set equal to zeroth-year litter ash weight. Standing litter biomass was estimated by summing  $y_t$  as estimated by equation 1 from year zero through the residence time of the litter.

Mineral contents of needles were means of P. balfouriana, P. contorta, and P. monticola needles produced between 1982 and 1986 and sampled during 1986. Mineral contents of wood were the mean of P. contorta wood produced in 1982 and 1985 and sampled in 1986. Mineral contents of bark were means of P. balfouriana, P. contorta, and P. monticola bark produced between 1982 and 1986 and sampled during 1986. Live branch mineral contents were estimated as simple means of wood and bark contents. Mineral contents of zeroth-year litter was assumed equal to that of live needles; mineral content of standing litter was summed from zeroth-year litter over the residence time of litter as estimated from equation 1. Mineral concentrations of roots were averaged from samples of P. monticola roots collected in 1988, with woody root mineral contents being simple means of 2-5, 5-10, 10-20, and 20-50 mm root size classes. Phosphorus content of roots was measured by emission spectroscopy.

### Wet Meadow Herbs

Two  $0.0314 \text{ m}^2$  subplots were placed within each of the major vegetation subtypes in each wet meadow plot. Biomass density of shoots was estimated from clippings harvested in 1986, and productivity from the difference between 1985 and 1986 clippings. Soil cores were sampled in July and August, 1985 (20 cm diameter), and July and September, 1986 (10 cm diameter cores). Roots biomass density was taken as the average over the four samplings, and root productivity as the difference in the sum of increments and sum of decrements among the four samplings. Above-ground live tissues and litter harvested in 1985 and 1986 were assayed for mineral content, and roots separated from the 1986 soil cores were assayed.

### Mesic Shrubs

Biomass distribution among above-ground components of *Phyllodoce breweri* was estimated from three  $314 \text{ cm}^2$  subplots within each of three plots sampled during September, 1985. Belowground biomass was estimated from cores sampled in July, 1985 and July, 1986. Productivity of above-ground components was estimated from representative branch samples collected the following year, and below-ground productivity was estimated by the difference of the sum of increments and the sum of decrements of root biomass in soil cores sampled in 1985 and 1986.

Mineral contents of above-ground tissues were means of *Phyllodoce* tissues sampled in 1985 and 1986. Mineral content of litter was not assayed. To estimate litter mineral content, it was assumed that the (litter mineral content/leaf mineral content) ratio of the wet meadow community would approximate that of the mesic shrubs. Then the product of the leaf mineral

content of Phyllodoce and the (litter mineral content/leaf mineral content) ratio of the wet meadows yields an estimate of mesic shrub litter mineral content. Salix roots harvested in 1987 were assayed for mineral content.

### Willows

The willow community was composed of Salix oreastera, other shrubs and annual herbs. The relative dominance (expressed as percent of community cover) of Salix, shrub, and herb groups within this community was estimated by the National Park Service from their permanent plots.

The distribution of biomass among the aboveground components of Salix was estimated from three 1 m<sup>2</sup> subplots within each of three plots harvested in September, 1985. Shrub biomass was derived by summing the aboveground biomass of mesic shrub tissues. Herb biomass was estimated from plots in the wet meadow communities. Belowground biomass was estimated from soil cores sampled in 1985 and 1986.

Mineral contents of Salix tissues were assayed in samples collected in 1985 and 1986. Shrub mineral contents were means of Phyllodoce tissues, weighted by biomass. Samples of wet meadow herbs collected in 1985 and 1986 were assayed for minerals. Mineral content of litter was estimated in the same manner as for the mesic shrub community, using Salix leaf mineral contents. Roots collected in 1987 were assayed for mineral content, with phosphorus assayed by optical emission spectroscopy.

### Mesic Rock Crevices

Biomass density estimates of Phyllodoce were applied to mesic rock crevice shrubs. Since vegetation cover within the crevices was 100%, the percent vegetation cover was set equal to the percent area of the rock crevices

occupying that area of the watershed. Mineral content of the above-ground shoots were taken as a weighted mean of the mineral contents of the aboveground tissues of Phyllodoce. Mineral contents of litter were assumed equal to those of Phyllodoce, and mineral contents of roots were taken as those of willow roots.

#### Xeric Rock Crevices

Shrub, herb and litter biomass was estimated from three plots sampled in 1987. Root biomass was set equal to willow root biomass. Shrub productivity was calculated as the product of shrub biomass and the biomass:productivity ratio established for Phyllodoce. Herb productivity was calculated as the product of herb biomass and the biomass:productivity established for wet meadow herbs. Litter productivity was calculated as shrub and herb productivity, using a weighted average of the biomass:productivity ratios of Phyllodoce and wet meadow herbs. Root productivity was estimated as the difference of the sum of increments and sum of decrements measured for Phyllodoce roots.

Shrub mineral contents were taken as a weighted mean of the mineral contents of Phyllodoce tissues. Mineral contents of herbs was taken as that of dry meadow herbs. Litter mineral content was not assayed. It was estimated assuming that the litter:leaf mineral content observed in the wet meadows approximated that in xeric rock crevices; litter mineral content was estimated as the product of mean of the shrub and herb mineral contents and the wet meadow litter:leaf ratio of mineral contents. Root mineral content was taken as that of Salix root mineral content.

### Dry Meadows, Fell Field, and Colluvium

Biomass, productivity, and mineral content data of xeric rock crevice herbs, litter, and roots were used.

### References

- Alexander, G.V., and L.T. McAnulty. 1981. Multielement analysis of Plant-related tissues and fluids by optical emission spectrometry. *J. Plant Nutr.* 3: 51-59.
- Gholz, H.L., C.C. Grier, A.G. Campbell, and A.T. Brown. 1979. Equations for estimating biomass and leaf area of plants in the Pacific Northwest. *For. Res. Lab.*, Oreg. State Univ., Corvallis, Ore. Res. Pap. 41.
- Pearson, J.A., T.J. Fahey, and D.H. Knight. 1984. Biomass and leaf area in contrasting lodgepole pine forests. *Can. J. For. Res.* 14: 259-265.
- Stark, N. 1972. Nutrient cycling pathways and litter fungi. *Biosci.* 22: 355-360.
- Westman, W.E. 1987. Aboveground biomass, surface area, and production relations of red fir (Abies magnifica) and white fir (A. concolor). *Can. J. For. Res.* 17: 311-319.

Table 7 . Notes for the sources of data presented in the biomass and nutrient pool tables for the Emerald Lake Basin.

Community Type	Density (g/m <sup>2</sup> )	Community biomass (kg/ha)	Watershed biomass (kg/ha)	Community productivity (kg/ha/yr)	Watershed productivity (kg/ha/yr)	Nitrogen	Phos- phorus	Sulfur	Trace elements
						(see 35, 38, 41)			
<b>Willow and Trees</b>									
Above-ground									
<u>Salix</u>									
Leaves	1	36	37	39	42	16	16	16	16
Twigs	1	36	37	39	42	17	17	17	17
New Wood	1	36	37	39	42	18	18	18	18
Reproductive	1	36	37	39	42	19	19	19	19
Old Wood	1	36	37	39	42	20	20	20	20
Dead Wood	1	36	37	39	42	21	21	21	21
Shrubs	43	36	37	39	42	29	29	29	29
Live Herbs	3	36	37	39	42	30	x	30	30
Litter	1	36	37	53	42	15	15	x	15
Below-ground	2	36	37	40	42	22	22	x	22
Mesic Shrubs									
Above-ground									
New Leaves	33	36	37	39	42	23	23	23	23
Twigs	33	36	37	39	42	24	24	24	24
New Wood	x	x	x	x	x	x	x	x	x
Reproductive	33	36	37	39	42	25	25	25	25
Old Leaves	33	36	37	39	42	26	26	26	26

Table 7 . (Continued)

Community Type	Density (g/m <sup>2</sup> )	Community biomass (kg/ha)	Watershed biomass (kg/ha)	Community produc- tivity (kg/ha/yr)	Watershed produc- tivity (kg/ha/yr)	Nitrogen (see 35, 38, 41)	Phos- phorus	Sulfur	Trace elements
Old Wood	33	36	37	39	42	27	27	27	27
Dead Wood	33	36	37	39	42	28	28	28	28
Litter	33	36	37	39	42	15	15	x	15
Below-ground	34	36	37	40	42	22	22	x	22
<b>Mesic Rock Crevices</b>									
Above-ground									
Shoot	43	36	37	39	42	29	29	29	29
Litter	43	36	37	39	42	44	44	x	44
Below-ground	43	36	37	40	42	22	22	x	22
<b>Wet Meadows</b>									
Above-ground									
Live Herbs	3	36	37	3	42	30	x	30	30
Litter	3	36	37	3	42	30	x	30	30
Below-ground	45	36	37	40	42	31	x	31	31
<b>Trees</b>									
Above-ground									
Needles	x	6 total/120	x	6	7	7	7	7	7
Live Branches	x	6 total/120	x	6	10	10	10	10	10
Wood	x	6 total/120	x	6	8	8	8	8	8
Bark	x	6 total/120	x	6	9	9	9	9	9
Litter	x	11 total/120	x	14	11	11	11	11	11
Below-ground	x	11 total/120	x	13	12	12	x	12	x

Table 7. (Continued)

Community Type	Density (g/m <sup>2</sup> )	Community biomass (kg/ha)	Watershed biomass (kg/ha)	Community productivity (kg/ha/yr)	Watershed productivity (kg/ha/yr)	Nitrogen	Phosphorus	Sulfur	Trace elements
<b>Xeric Rock Crevices</b>									
Above-ground									
Shrubs	43	36	37	47	42	29	29	29	29
Live Herbs	4	36	37	48	42	x	32	x	32
Litter	4	36	37	49	42	46	46	x	46
Below-ground	54	36	37	50	42	22	22	x	22
Dry Meadows									
Above-ground									
Live Herbs	5	36	37	48	42	x	32	x	32
Litter	5	36	37	48	42	x	51	x	51
Below-ground	54	36	37	50	42	22	22	x	22
Fall Field									
Above-ground									
Live Herbs	5	36	37	48	42	x	32	x	32
Litter	5	36	37	48	42	x	51	x	51
Below-ground	54	36	37	50	42	22	22	x	22
Colluvium									
Above-ground									
Live Herbs	5	36	37	48	42	x	32	x	32
Litter	5	36	37	48	42	x	51	x	51
Below-ground	54	36	37	50	42	22	22	x	22

Table 8.

Footnotes (species and community abbreviations as in text):

1. Rundel et al., 1988, Table 16, p. 55 for Salix oreastera above-ground biomass.
2. Rundel et al., 1988, Tables 2 & 6, p. 25 & 29. Mean of early and late 1985 & 1986 combined plots.
3. 1986 data, GHM.
4. 1987 data, dry rock crevices (RCH).
5. Mean of 1986, 1987 data dry meadow, GHX.
6. Herman et al., 1989, Table 1.
7. Mean of mineral concentrations of PIBA-N, PICO-N, PIMO-N.
8. Mean of mineral concentrations of PICO-W.
9. Mean of mineral concentrations of PIBA-BK, PICO-BK, PIMO-BK.
10. Simple mean of 8 & 9.
11. Herman et al., 1989.
12. Woody roots are simple mean of 2-5, 5-10, 10-20, & 20-50 mm root mineral concentrations. Phosphorus is from arc system.
13. Simple mean of productivity % of above-ground parts, Herman et al., 1989, Table I.
14. Simple mean of Mary Lueking's data from PIMO stand, 1985-1986.
15. Assume (litter/leaf) mineral concentrations of wet meadows approximate that of Salix or Phyllodoce or GHX. So (litter conc/leaf conc) wet meadow x (leaf conc) salix or Phyllodoce or GHX = (litter conc) Salix or Phyllodoce or GHX.
16. 85, 86 SAOR-NL
17. 85, 86 SAOR-CT
18. 85, 86 SAOR-BW&BK
19. 85, 86 SAOR-RE
20. 85, 86 SAOR-OT
21. 85, 86 SAOR-DW
22. 87 SAOR roots: N is from our lab, all other elements, including P is from arc system.
23. 85, 86 PHBR-NL
24. 85, 86 PHBR-CT
25. 85, 86 PHBR-RE
26. 85, 86 PHBR-OL
27. 85, 86 PHBR-OT
28. 85, 86 PHBR-DW
29. Weighted mean of 23 through 28, or of Phyllodoce roots.
30. 85, 86 GHM
31. 86 GHM roots
32. GHX 87, arc system
33. Rundel et al., Table 15, p. 54.
34. Rundel et al., Tables 3 & 7, pp. 26 & 30.
35. Mineral capitals (community basis  $\text{kg}\cdot\text{ha}^{-1}$ ) = biomass ( $\text{kg}\cdot\text{ha}^{-1}$ ) x mineral concentration ( $\text{mg}\cdot\text{kg}^{-1}$ )  $\times 10^{-6}$   $\text{kg}\cdot\text{mg}^{-1}$ .
36. Biomass (community basis  $\text{kg}\cdot\text{ha}^{-1}$ ) = density ( $\text{g}\cdot\text{m}^{-2}$ ) x (% cover/100)  $\times 10 \text{ kg}\cdot\text{m}^{-2}\cdot\text{g}^{-1}\cdot\text{ha}^{-1}$ .
37. Biomass (watershed basis  $\text{kg}\cdot\text{ha}^{-1}$ ) = community biomass x community area / watershed area.

Table 8. (Continued)

Footnotes (Continued)

38. Mineral capitals (watershed basis  $\text{kg}\cdot\text{ha}^{-1}$ ) = community capital x community area - watershed area.
39. Community productivity = community biomass x above-ground Productivity: Biomass ratio from Rundel et al., 1988, Table 12, p. 51.
40. Difference between sum of decrements and sum of increments (Rundel et al., 1988, Table 11, p. 38) x (% cover/100).
41. Mineral fluxes = productivity ( $\text{kg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ ) x mineral concentration ( $\text{mg}\cdot\text{kg}^{-1}$ ) x  $10^{-6}$   $\text{kg}\cdot\text{mg}^{-1}$ .
42. Productivity (watershed basis  $\text{kg}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$ ) = community productivity x community area / watershed area.
43. Sum of above-ground, litter, or root tissues of Phyllodoce.
44. Concentrations of Phyllodoce litter.
45. Rundel et al., 1988, Tables 1 & 5, pp. 24 & 28, mean of early and late 1985 & 1986 combined plots.
46. Assume (litter mineral conc/leaf mineral conc) wet meadow = (litter mineral conc/leaf mineral conc) xeric rock crevice, so (litter mineral conc) xrc = (litter mineral conc/leaf mineral conc) wet meadow x (mean of shrub & live herb mineral conc) xrc.
47. Productivity = biomass x Productivity:Biomass ratio for Phyllodoce, Rundel et al., 1988, Table 12, p. 51.
48. Productivity = biomass x Productivity:Biomass ratio for wet meadow, Rundel et al., 1988, Table 12, p. 51.
49. Litter productivity is computed as in 47 and 48, using a weighted mean productivity:biomass ratio for Phyllodoce and wet meadows.
50. Rundel et al., 1988, difference of sum of decrements and increments for Phyllodoce.
51. Assume (litter mineral conc/leaf mineral conc) wet meadow = (litter mineral conc/leaf mineral conc) dry meadow, so that (litter mineral conc) dry meadow = (litter mineral conc/leaf mineral conc) wet meadow x (live herb mineral conc) dry meadow.
52. Data from National Park Service.
53. Litter productivity is computed as in 47 and 48, using a weighted mean productivity:biomass ratio for Phyllodoce, Salix, and wet meadows.
54. The ratio of belowground:aboveground productivity for wet meadow herbs (2.86) was applied to total aboveground productivity to derive belowground productivity.

## Community and Watershed Nutrient Pools and Fluxes

Using the methods of data collection, analyses and extrapolations described in the previous chapter, it is possible to estimate community and watershed levels of standing pools and fluxes for biomass and nutrients in the terrestrial vegetation of the Emerald Lake watershed. Total biomass and mineral concentrations (mg/kg dry weight) for nine plant communities are presented in Tables 13-21. Biomass and mineral pool sizes on a community basis (kg/ha of community type) are presented in Tables 22-29, and these same parameters for productivity/flux on a community basis in Tables 30-37. Biomass and mineral pools on a watershed basis for each community type are given in Tables 38-46, and productivity/flux values for the watershed in Tables 47-55.

Conifers comprise the overwhelmingly dominant component of biomass and nutrient pools in the Emerald Lake basin (Table 9). These trees comprise 90.5% of the total above-ground biomass and 73.1% of the below-ground biomass in the basin. Overall, even with a small litter pool, the conifers comprise 84.7% of the basin biomass. The willow thicket community is second in importance with 7.7% of the basin biomass, and the wet meadow communities total 4.6% of this pool. Overall, these three communities account for all but 3% of the basin biomass.

Nutrient pools for nitrogen, phosphorus, sulfur, major cations and trace elements roughly follow the distributions for total biomass in the basin. Root tissues are proportionally lower in total nitrogen and higher in phosphorus and aluminum than above-ground tissues. Some of this difference may be an artefact of residual soil contamination in washed root samples.

Net annual fluxes for biomass and minerals in the Emerald Lake basin can be estimated well for above-ground tissues, but with far greater uncertainty for below-ground tissues. The level of biological activity and growth below-ground is of critical importance in understanding the role of terrestrial vegetation in influencing biogeochemical cycles in the watershed. We estimate that 60-70% of the total net productivity takes place in below-ground tissues.

For above-ground productivity and mineral fluxes, conifers remain the dominant vegetation element, but with reduced importance from the biomass distribution (Table 10). Much of the biomass distribution of conifers is tied up with non-productive woody tissues as contrasted with the wet meadow communities with very little perennial above-ground tissues. For above-ground tissues, conifers comprise 61.6% of the net annual productivity, followed by 14.7% in the willow thickets, and 13.6% in the wet meadows. Together these three community types form 89.9% of the productivity for the entire basin.

For net annual nitrogen flux in above-ground tissues, conifers make up only 48.6% of the basin total (Table 11). Wet meadows are second in importance with 29.6%, followed by willow thickets with 15.8%. These three total 94% of basin-wide nitrogen flux. The distribution of net above-ground phosphorus fluxes among communities in the Emerald Lake watershed closely follow those for nitrogen (Table 12). These values are 50.0%, 21.8% and 10.2% for conifer, wet meadow and willow thicket communities, respectively.

While our data on below-ground productivity is less reliable, particularly at this stage for the willow community, it appears that the significance of the wet meadow, willow thicket and dry meadow communities are all

disproportionately high when below-ground processes are factored in. The overall importance of conifers in basin-wide nutrient fluxes drops well below 50% when total productivity is considered.

Our conclusions are that biogeochemical models of terrestrial mineral fluxes in the Emerald Lake watershed need to focus largely on three community types--conifers (as individual populations), wet meadows, and willow thickets. Other communities comprise only a small part of total biomass, mineral pools and productivity/flux rates. For individual subdivisions of the basin, however, other communities may be significant, particularly the dry meadow community.

Table 9. Above-ground, below-ground, and litter biomass for vegetation types within the Emerald Lake Watershed. All values are in kg/ha.

<u>Community</u>	<u>Above-ground</u>	<u>Below-ground</u>	<u>Litter</u>
Willow	965.4	567.7	439.1
Mesic shrub	26.5	42.4	29.5
Mesic crevice	36.9	58.8	40.9
Wet meadow	130.0	999.5	47.3
Xeric crevice	6.0	33.0	48.7
Dry meadow	62.9	361.3	49.7
Fell field	0.4	2.1	0.3
Colluvium	1.5	8.5	1.2
Trees	<u>16045.1</u>	<u>5637.6</u>	<u>37.7</u>
Total	17274.7	7710.1	694.4

Table 10. Above-ground and litter productivity for vegetation types within the Emerald Lake Watershed. All values are in kg/ha/yr.

<u>Community</u>	<u>Above-ground</u>	<u>Litter</u>
Willow	119.4	102.2
Mesic shrub	8.2	9.1
Mesic crevice	11.4	12.6
Wet meadow	109.7	47.3
Xeric crevice	3.5	28.4
Dry meadow	56.7	44.7
Fell field	0.3	0.3
Colluvium	1.3	1.0
Trees	<u>497.8</u>	<u>9.0</u>
Total	808.3	254.6

Table 11. Net annual uptake of nitrogen by above-ground and litter for vegetation types within the Emerald Lake Watershed. All values are in kg/ha/yr.

<u>Community</u>	<u>Above-ground</u>	<u>Litter</u>
Willow	1.00	2.59
Mesic shrub	0.06	0.12
Mesic crevice	0.10	0.17
Wet meadow	1.87	0.72
Xeric crevice	0.05	0.21
Dry meadow	0.15	0.50
Fell field	+	+
Colluvium	0.02	0.01
Trees	<u>3.07</u>	<u>0.39</u>
Total	6.32	4.71

Table 12. Net annual uptake of phosphorus by above-ground and litter for vegetation types within the Emerald Lake Watershed. All values are in kg/ha/yr.

<u>Community</u>	<u>Above-ground</u>	<u>Litter</u>
Willow	0.08	0.10
Mesic shrub	+	0.01
Mesic crevice	0.01	0.01
Wet meadow	0.17	0.04
Xeric crevice	0.01	0.02
Dry meadow	0.12	0.05
Fell field	+	+
Colluvium	+	+
Trees	<u>0.39</u>	<u>0.03</u>
Total	0.78	0.26

Table 13. Emerald Lake Trees: Total biomass and mineral concentrations.

Tissue	Biomass (kg)	N (mg/kg)	S (mg/kg)	P (mg/kg)	Na (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
Needles	45805.15	10906.67	866	940	62.6147	4012.899	2939.241	1102.419
Live Branch	734169.3	6103.333	741.8333	798.3333	78.28929	6019.508	1746.361	1180.375
Stem Wood	943479.3	4800	565	650	54.91667	5485	695.8333	883.5
Stem Bark	201977.4	7406.667	918.6667	946.6667	101.6619	6554.016	2796.889	1477.251
Litter	4520.285	42953.15	3410.522	3701.952	246.5921	15803.79	11575.46	4341.598
Fine Roots	156116	4650		6327.778	2286.222	8058.889	1244.778	1384.667
Woody Roots	520386.8	3800		4305.455	2491.045	5719.091	1767.091	1248.909

Tissue	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	B (mg/kg)	Al (mg/kg)	Si (mg/kg)	Ti (mg/kg)
Needles	19.9707	7.593937	148.7425	272.8576	30.25476	358.6648	368.2429	2.622063
Live Branch	28.29524	8.53527	124.2802	118.268	34.13683	226.781	500.4853	3.13919
Stem Wood	22.13333	7.138333	64.15	109.25	35.08333	118.6333	174.0833	0.603333
Stem Bark	34.45714	9.932206	184.4103	127.286	33.19032	334.9286	826.8873	5.675048
Litter	78.64954	29.9068	585.7848	1074.581	119.1507	1412.51	1450.231	10.32633
Fine Roots	6.56	13.74444	1654.444	579.6667	11.68778	6452.222	13640	144.4889
Woody Roots	5.395455	8.745455		1002	571.5455	8.679091	3054.182	11218.18

Tissue	V (mg/kg)	Co (mg/kg)	Ni (mg/kg)	Mo (mg/kg)	Cr (mg/kg)	Sr (mg/kg)	Ba (mg/kg)	Li (mg/kg)
Needles	2.093825	1.141556	1.590365	0.369587	0.088889	13.00829	5.233762	0.674587
Live Branch	1.925333	0.521817	0.684825	0.242556	0.028929	11.34364	5.919563	0.519087
Stem Wood	1.908333	0	0.251667	0.098333	0	5.365	2.006667	0.436667
Stem Bark	1.942333	1.043635	1.117984	0.386778	0.057857	17.32229	9.83246	0.601508
Litter	8.246001	4.495728	6.26325	1.455526	0.350066	51.22984	20.61185	2.656691
Fine Roots	0.064444	0.83	2.042222	2.983333	1.452222	7.017778	62.75556	0.714444
Woody Roots	0.042727	0.106364	1.299091	2.034545	1.269091	7.02	47.96727	0.415455

Tissue	Ag (mg/kg)	Sn (mg/kg)	Pb (mg/kg)	Be (mg/kg)	Cd (mg/kg)	As (mg/kg)
Needles	0	1.157492	21.61527	0.006476	0.081429	0.026492
Live Branch	0	1.14373	15.95915	0.011667	0.164667	0.02331
Stem Wood	0	1.08	8.905	0.001667	0.116667	0.013333
Stem Bark	0	1.20746	23.0133	0.021667	0.212667	0.033286
Litter	0	4.55849	85.12627	0.025505	0.320686	0.104332
Fine Roots	0.43	1.46	2.736667		0.124444	0.32
Woody Roots	0.700909	1.336364	4.21		0	0.321818

Table 14. Emerald Lake Willows concentrations.

## Biomass density and mineral

Tissue	Density (g/m <sup>2</sup> )	N ( $\mu$ g/g)	S ( $\mu$ g/g)	P ( $\mu$ g/g)	NA ( $\mu$ g/g)	K ( $\mu$ g/g)	CA ( $\mu$ g/g)	MG ( $\mu$ g/g)
SAOR-NL								
mean	75.7	28200	1915	1900	46.3	8720	11010	2020
std	18.15	6600	5	400	12.59802	1774.721	2078.742	323.4192
n	9	2	2	2	6	6	6	6
SAOR-CT								
mean	61.89	13500	980	1600	18.45	5356.667	4091.667	1165.833
std	34.38	700	130	200	4.173228	2276.918	2131.787	301.1425
n	9	2	2	2	6	6	6	6
SAOR-NW								
mean	131.74	6200	620	900	23.76667	1794.5	3807.833	541.3333
std	60.48	2500	100	100	4.741191	1088.543	3649.281	253.6307
n	9	2	2	2	6	6	6	6
SAOR-RE								
mean	4.76	16900	1280	2700	67.6	7361.667	2225.333	1019.5
std	4.88	1100	10	500	45.53061	2833.34	1309.909	285.7002
n	9	2	2	2	6	6	6	6
SAOR-OT								
mean	1956.35	6366.667	643.3333	800	22.56111	1586.444	3415.222	518.8889
std	954.16	2054.805	88.06563	163.2993	6.313028	944.9482	3040.627	216.4719
n	9	3	3	3	9	9	9	9
SAOR-DW								
mean	1130.04	5200	940	200	16.58667	2100	7770	779
std	509.08	0	0	0	8.69339	537.4632	1454.166	39.7576
n	9	1	1	1	3	3	3	3
Shrubs								
mean	1460.17	8383.9	879.3419	764.3843	116.0236	6500.653	4522.21	1046.61
std								
n								
Live Herbs								
mean	377	17013.64		1609.091	386.7766	21484.67	9119.402	2331.261
std		6013.265		1286.789	582.5263	18748.34	5371.484	872.9532
n		44		44	184	184	184	184
SAOR-LITT								
mean	1141.3	25376.23		1003.672	121.3551	3002.515	5907.745	1325.812
std		871.35						
n		9						
SAOR 0- 2mm								
mean	612	14900		14400	10185.56	25515	5663.889	2740
std	283			3925.557	4774.059	18863.16	2742.88	889.5692
n	4	1		18	18	18	18	18
SAOR 2- 5mm								
mean	141	8600		8488.462	4068.923	8037.692	6986.154	1345.692
std	20	5400		3259.809	3617.581	7066.406	4501.262	641.4837
n	4	2		13	13	13	13	13
SAOR 5-10mm								
mean	201	8700		11800	14320	27085	3275	1575
std	129			200	9980	22815	775	555
n	4	1		2	2	2	2	2

SAOR 10-20mm

mean	191	5875	1111	1815	4075	753.5
std	69	955	719	445	405	366.5
n	4	2	2	2	2	2

SAOR 20-50mm

mean	331
std	201
n	4





Tissue	AG ( $\mu\text{g/g}$ )	SN ( $\mu\text{g/g}$ )	PB ( $\mu\text{g/g}$ )	BE ( $\mu\text{g/g}$ )	CD ( $\mu\text{g/g}$ )	AS ( $\mu\text{g/g}$ )
SAOR-NL						
mean	0	0.485	10.93833		0 0.066667	0
std	0	0.328164	1.641853		0 0.149071	0
n	6	6	6	6	6	6
SAOR-CT						
mean	0	0.823333	7.405	0.016667	0 0.001667	
std	0	0.141853	1.153715	0.024267	0 0.003727	
n	6	6	6	6	6	6
SAOR-NW						
mean	0	0.931667	7.465	0.028333	0	0
std	0	0.456706	3.038046	0.021922	0	0
n	6	6	6	6	6	6
SAOR-RE						
mean	0.001667	0.998333	9.005	0.016667	0.206667	0
std	0.003727	0.309592	1.61501	0.020548	0.295052	0
n	6	6	6	6	6	6
SAOR-OT						
mean	0	0.972222	7.222222	0.028889	0	0
std	0	0.409275	2.970622	0.018526	0	0
n	9	9	9	9	9	9
SAOR-DW						
mean	0	0.633333	9.283333	0	0	0
std	0	0.369354	4.565876	0	0	0
n	3	3	3	3	3	3
Shrubs						
mean	0	0.579366	8.027974		1.163483	0.000277
std						
n						
Live Herbs						
mean	0.471087	0.584783	10.32554	0.364239	2.153424	0.195
std	0.639014	0.468412	7.442724	0.482335	4.693539	0.102177
n	184	184	184	184	184	184
SAOR-LITT						
mean	0	0.872344	4.380721		0	0
std						
n						
SAOR 0- 2mm						
mean	0.008889	1.293333	23.00944		26.38833	0.214444
std	0.03665	0.297583	11.10382		33.11299	0.07065
n	18	18	18		18	18
SAOR 2- 5mm						
mean	0.16	1.289231	7.591538		10.72615	0.312308
std	0.28887	0.406362	4.639134		11.50016	0.091244
n	13	13	13		13	13
SAOR 5-10mm						
mean	0	1.485	7.7		14.3	0.28
std	0	0.095	7.7		2.9	0.11
n	2	2	2		2	2
SAOR 10-20mm						
mean	0.43	1.445	3.91		6.9	0.38
std	0.07	0.165	0.02		6.9	0.01
n	2	2	2		2	2

Table 15. Emerald Lake Mesic Rock Crevices: Biomass density and mineral concentrations.

Tissue	Density (g/m <sup>2</sup> )	N ( $\mu\text{g/g}$ )	S ( $\mu\text{g/g}$ )	P ( $\mu\text{g/g}$ )	NA ( $\mu\text{g/g}$ )	K ( $\mu\text{g/g}$ )	CA ( $\mu\text{g/g}$ )	MG ( $\mu\text{g/g}$ )
Live Shoot	1460.17	8383.9	879.3419	764.3843	116.0236	6500.653	4522.21	1046.61
Litter	1618.48	13408.01			898.0226	129.6115	2988.742	2848.345
Roots	2329	12169.46			11756.02	8745.704	19674.95	5263.695
							2012.057	

Tissue	ZN ( $\mu\text{g/g}$ )	CU ( $\mu\text{g/g}$ )	FE ( $\mu\text{g/g}$ )	MN ( $\mu\text{g/g}$ )	B ( $\mu\text{g/g}$ )	AL ( $\mu\text{g/g}$ )	SI ( $\mu\text{g/g}$ )	TI ( $\mu\text{g/g}$ )
Live Shoot	18.16053	6.386795	390.8569	431.4911	16.94364	466.8876	3459.655	16.57282
Litter	92.52535	8.339018	3156.26	522.9126	10.73234	1694.976	5036.925	45.58543
Roots	39.1911	29.05181	2590.207	1534.656	9.126245	8297.424	16193.51	418.4667

Tissue	V ( $\mu\text{g/g}$ )	CO ( $\mu\text{g/g}$ )	NI ( $\mu\text{g/g}$ )	MO ( $\mu\text{g/g}$ )	CR ( $\mu\text{g/g}$ )	SR ( $\mu\text{g/g}$ )	BA ( $\mu\text{g/g}$ )	LI ( $\mu\text{g/g}$ )
Live Shoot	0.417226	0.22013	0.516799	0.249056	0.195128	32.11156	73.07809	0.126084
Litter	0.980258	9.423208	0.638983	0.338339	0.341263	21.55257	77.8753	4.55373
Roots	2.786374	1.850973	5.465628	6.233133	2.458966	28.99135	111.0153	5.489877

Tissue	AG ( $\mu\text{g/g}$ )	SN ( $\mu\text{g/g}$ )	PB ( $\mu\text{g/g}$ )	BE ( $\mu\text{g/g}$ )	CD ( $\mu\text{g/g}$ )	AS ( $\mu\text{g/g}$ )
Live Shoot	0	0.579366	8.027974		0	1.163483
Litter	0	1.208092	3.039071		0	0
Roots	0.085926	1.347771	14.82836		0	18.74035
						0.265485

Table 16. Emerald Lake Mesic Shrubs: Biomass density and mineral concentrations.

Tissue	Density (g/m <sup>2</sup> )	N ( $\mu$ g/g)	S ( $\mu$ g/g)	P ( $\mu$ g/g)	NA ( $\mu$ g/g)	K ( $\mu$ g/g)	CA ( $\mu$ g/g)	MG ( $\mu$ g/g)
New Leaves								
mean	248.17	14900	1205	1700	49.45	8680	5308.333	1593.333
std	100.76	0	5	200	23.91797	777.0886	1140.751	222.1611
n	9	2	2	2	6	6	6	6
New Twigs								
mean	71.9	10500	975	1650	157.7167	9105	5420	1200
std	24.69	1000	5	50	74.78076	782.9378	1227.396	67.33003
n	9	2	2	2	6	6	6	6
Reproductive								
mean	8.84	11600	1210	1400	35.2	7566.667	4920	1166.667
std	9.56	0	0	0	5.494239	293.2955	435.9664	16.99673
n	9	1	1	1	3	3	3	3
Old Leaves								
mean	242.44	10500	1020	800	475.7	9091.667	5140	1578.333
std	122.82	500	20	100	455.2863	929.9716	1182.681	321.3729
n	9	2	2	2	6	6	6	6
Old Twigs								
mean	684.22	5600	655	450	27.61667	5283.333	3516.667	698.8333
std	403.79	200	155	150	5.139201	194.4794	732.727	69.36237
n	9	2	2	2	6	6	6	6
Dead Wood								
mean	204.6	6400	1020	300	55.06667	3896.667	5866.667	857.3333
std	102.88	0	0	0	19.48971	571.567	458.7907	119.5696
n	9	1	1	1	3	3	3	3
Litter								
mean	1618.48	13408.01		898.0226	129.6115	2988.742	2848.345	1045.773
std	1046.14							
n	9							
0- 2mm Roots								
mean	1147	14900		14400	10185.56	25515	5663.889	2740
std	526			3925.557	4774.059	18863.16	2742.88	889.5692
n	4	1		18	18	18	18	18
2- 5mm Roots								
mean	441	8600		8488.462	4068.923	8037.692	6986.154	1345.692
std	248	5400		3259.809	3617.581	7066.406	4501.262	641.4837
n	4	2		13	13	13	13	13
5-10mm Roots								
mean	449	8700		11800	14320	27085	3275	1575
std	247			200	9980	22815	775	555
n	4	1		2	2	2	2	2
10-20mm Roots								
mean	274			5875	1111	1815	4075	753.5
std	201			955	719	445	405	366.5
n	4			2	2	2	2	2
20-50mm Roots								
mean	18							
std	24							
n	4							





Tissue	AG ( $\mu\text{g/g}$ )	SN ( $\mu\text{g/g}$ )	PB ( $\mu\text{g/g}$ )	BE ( $\mu\text{g/g}$ )	CD ( $\mu\text{g/g}$ )	AS ( $\mu\text{g/g}$ )
New Leaves						
mean	0 0.671667	7.588333		0 0.898333	0	
std	0 0.43349	2.371985		0 0.531175	0	
n	6 6	6		6 6	6	
New Twigs						
mean	0 0.548333	8.016667		0 1.63	0	
std	0 0.158263	0.934909		0 1.030566	0	
n	6 6	6		6 6	6	
Reproductive						
mean	0 0.63	8.96		0 0.49	0	
std	0 0.184029	2.488413		0 0.123558	0	
n	3 3	3		3 3	3	
Old Leaves						
mean	0 0.375	10.325		0 2.903333	0.001667	
std	0 0.19721	3.358907		0 1.8218	0.003727	
n	6 6	6		6 6	6	
Old Twigs						
mean	0 0.636667	6.973333		0 0.468333	0	
std	0 0.186875	1.686077		0 0.338891	0	
n	6 6	6		6 6	6	
Dead Wood						
mean	0 0.526667	9.33		0 1.613333	0	
std	0 0.247835	2.336764		0 0.175563	0	
n	3 3	3		3 3	3	
Litter						
mean	0 1.208092	3.039071		0 0	0	
std						
n						
0- 2mm Roots						
mean	0.008889	1.293333	23.00944		26.38833	0.214444
std	0.03665	0.297583	11.10382		33.11299	0.07065
n	18	18	18		18	18
2- 5mm Roots						
mean	0.16	1.289231	7.591538		10.72615	0.312308
std	0.28887	0.406362	4.639134		11.50016	0.091244
n	13	13	13		13	13
5-10mm Roots						
mean	0	1.485	7.7		14.3	0.28
std	0	0.095	7.7		2.9	0.11
n	2	2	2		2	2
10-20mm Roots						
mean	0.43	1.445	3.91		6.9	0.38
std	0.07	0.165	0.02		6.9	0.01
n	2	2	2		2	2

Table 17. Emerald Lake Wet Meadow Herbs: Biomass density and mineral concentrations.

Sample	Density (g/m <sup>2</sup> )	N ( $\mu$ g/g)	P ( $\mu$ g/g)	NA ( $\mu$ g/g)	K ( $\mu$ g/g)	CA ( $\mu$ g/g)	MG ( $\mu$ g/g)	ZN ( $\mu$ g/g)
85 Live Herbs								
mean	353	13965	935	288.0494	19130.79	10050.67	2252.562	20.71528
std		2401.723	473.5768	436.7496	15599.15	5342.04	834.477	20.04884
n		20	20	89	89	89	89	89
86 Live Herbs								
mean	377	19554.17	2170.833	479.2684	23689.89	8246.947	2404.989	22.08347
std		6876.468	1467.844	678.8614	21042.37	5251.162	901.3075	18.30642
n		24	24	95	95	95	95	95
85-86 L Herbs								
mean	377	17013.64	1609.091	386.7766	21484.67	9119.402	2331.261	21.42168
std		6013.265	1286.789	582.5263	18748.34	5371.484	872.9532	19.1812
n		44	44	184	184	184	184	184
85,86 Litter								
mean	251	15310	850	1013.765	7397.712	4893.288	1530.106	79.33485
std		3635.918	372.1559	774.9127	8043.876	2158.212	496.5205	49.26088
n		20	20	66	66	66	66	66
0- 2mm Roots								
mean	1859	8800	11696	7068.667	13316	3012.667	1791.333	81.06667
std		955	140	3229.881	5355.659	13609.53	1229.919	317.0461
n		4	2	15	15	15	15	15
2- 5mm Roots								
mean	706							
std		227						
n		4						
5-10mm Roots								
mean	292							
std		112						
n		4						
10-20mm Roots								
mean	40							
std		31						
n		4						





Sample	SN ( $\mu\text{g/g}$ )	PB ( $\mu\text{g/g}$ )	BE ( $\mu\text{g/g}$ )	CD ( $\mu\text{g/g}$ )	AS ( $\mu\text{g/g}$ )
85 Live Herbs					
mean	0.538427	10.34371	0.438764	3.065955	0.193371
std	0.337099	6.219959	0.411344	5.05479	0.070726
n	89	89	89	89	89
86 Live Herbs					
mean	0.628211	10.30853	0.294421	1.298526	0.196526
std	0.560896	8.4288	0.531042	4.149598	0.12462
n	95	95	95	95	95
85-86 L Herbs					
mean	0.584783	10.32554	0.364239	2.153424	0.195
std	0.468412	7.442724	0.482335	4.693539	0.102177
n	184	184	184	184	184
85,86 Litter					
mean	1.051818	4.135303	0.075758	0	0.241061
std	0.381401	5.441009	0.264804	0	0.055217
n	66	66	66	66	66
0- 2mm Roots					
mean	1.29	14.32		29.14133	0.246667
std	0.286287	6.248629		40.80984	0.045558
n	15	15		15	15
2- 5mm Roots					
mean					
std					
n					
5-10mm Roots					
mean					
std					
n					
10-20mm Roots					
mean					
std					
n					

Table 18. Emerald Lake Xeric Rock Crevices: Biomass density and mineral concentrations.

Tissue	Density (g/m <sup>2</sup> )	N ( $\mu$ g/g)	S ( $\mu$ g/g)	P ( $\mu$ g/g)	NA ( $\mu$ g/g)	K ( $\mu$ g/g)	CA ( $\mu$ g/g)	MG ( $\mu$ g/g)
<b>Aboveground</b>								
Shrubs	289	8383.9	879.3419	764.3843	116.0236	6500.653	4522.21	1046.61
Live Herbs	248			1923.182	247.6591	19404.09	10589.09	2520.045
Litter	2281	7544.39		709.8515	476.6173	4459.827	4054.21	1170.474
Roots	1476	10733.33		10140.87	7421.37	15613.17	5000.011	1603.548

Tissue	ZN ( $\mu$ g/g)	CU ( $\mu$ g/g)	FE ( $\mu$ g/g)	MN ( $\mu$ g/g)	B ( $\mu$ g/g)	AL ( $\mu$ g/g)	SI ( $\mu$ g/g)	TI ( $\mu$ g/g)
<b>Aboveground</b>								
Shrubs	18.16053	6.386795	390.8569	431.4911	16.94364	466.8876	3459.655	16.57282
Live Herbs	22.88682	4.408182	299.9545	315.6727	27.89773	440.8955	4541	34.99909
Litter	76.00908	8.047035	2552.143	802.811	9.794831	2222.442	8016.983	130.5104
Roots	34.01528	24.83406	2371.442	1377.051	9.279177	6287.205	14502.44	313.4616

Tissue	V ( $\mu$ g/g)	CO ( $\mu$ g/g)	NI ( $\mu$ g/g)	MO ( $\mu$ g/g)	CR ( $\mu$ g/g)	SR ( $\mu$ g/g)	BA ( $\mu$ g/g)	LI ( $\mu$ g/g)
<b>Aboveground</b>								
Shrubs	0.417226	0.22013	0.516799	0.249056	0.195128	32.11156	73.07809	0.126084
Live Herbs	0.404545		0	0.640455	2.460455	0.431818	155.3591	75.76364
Litter	6.9047	6.349984	2.263668	2.148592	0.867378	74.27342	105.3098	3.055917
Roots	2.220545	1.683611	4.799081	5.335801	1.992137	22.91401	97.7656	3.762051

Tissue	AG ( $\mu$ g/g)	SN ( $\mu$ g/g)	PB ( $\mu$ g/g)	BE ( $\mu$ g/g)	CD ( $\mu$ g/g)	AS ( $\mu$ g/g)	
<b>Aboveground</b>							
Shrubs	0	0.579366	8.027974		0	1.163483	0.000277
Live Herbs	0.492727	0.68	13.92227			1.705909	0.480909
Litter	0.084705	1.132578	4.395455		0	0	0.297423
Roots	0.149722	1.378141	10.55275				

Table 19. Emerald Lake Dry Meadow: Biomass density and mineral concentrations.

Tissue	AG ( $\mu\text{g/g}$ )	SN ( $\mu\text{g/g}$ )	PB ( $\mu\text{g/g}$ )	BE ( $\mu\text{g/g}$ )	CD ( $\mu\text{g/g}$ )	AS ( $\mu\text{g/g}$ )
Live Herbs						
mean	0.492727	0.68	13.92227		1.705909	0.480909
std	0.22694	0.29147	5.331525		1.594746	0.101126
n	22	22	22		22	22
Litter						
mean	0.16941	1.223081	5.575766		0	0.594504
std						
n						
Roots						
mean	0.149722	1.378141	10.55275			
std						
n						

Table 20 .Emerald Lake Fell Field: Biomass density and mineral concentrations.

Tissue	AG ( $\mu\text{g/g}$ )	SN ( $\mu\text{g/g}$ )	PB ( $\mu\text{g/g}$ )	BE ( $\mu\text{g/g}$ )	CD ( $\mu\text{g/g}$ )	AS ( $\mu\text{g/g}$ )
<b>Live Herbs</b>						
mean	0.492727	0.68	13.92227		1.705909	0.480909
std	0.22694	0.29147	5.331525		1.594746	0.101126
n	22	22	22		22	22
<b>Litter</b>						
mean	0.16941	1.223081	5.575766		0	0.594504
std						
n						
<b>Roots</b>						
mean	0.149722	1.378141	10.55275			
std						
n						

Table 21. Emerald Lake Colluvium: Biomass density and mineral concentrations.

Tissue	AG ( $\mu\text{g/g}$ )	SN ( $\mu\text{g/g}$ )	PB ( $\mu\text{g/g}$ )	BE ( $\mu\text{g/g}$ )	CD ( $\mu\text{g/g}$ )	AS ( $\mu\text{g/g}$ )
Live Herbs						
mean	0.492727	0.68	13.92227		1.705909	0.480909
std	0.22694	0.29147	5.331525		1.594746	0.101126
n	22	22	22		22	22
Litter						
mean	0.16941	1.223081	5.575766		0	0.594504
std						
n						
Roots						
mean	0.149722	1.378141	10.55275			
std						
n						

Table 22. Emerald Lake Willows  
community basis.

## Biomass and mineral capitals.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
Aboveground								
<del>Salix</del>								
New Leaves	272.52	7.685064	0.521876	0.517788	0.012618	2.376374	3.000445	0.55049
New Twigs	222.804	3.007854	0.218348	0.356486	0.004111	1.193487	0.91164	0.259752
New Wood	474.264	2.940437	0.294044	0.426838	0.011272	0.851067	1.805918	0.256735
Reproductive	17.136	0.289598	0.021934	0.046267	0.001158	0.12615	0.038133	0.01747
Old Twigs	7042.86	44.83954	4.530907	5.634288	0.158895	11.17311	24.05293	3.654462
Dead Wood	4068.144	21.15435	3.824055	0.813629	0.067477	8.543102	31.60948	3.169084
Shrubs	1460.17	12.24192	1.283989	1.116131	0.169414	9.492058	6.603195	1.528228
Live Herbs		263.9	4.489899		0.424639	0.10207	5.669805	2.40661
Litter	6163.02	156.3942			6.185653	0.747914	18.50456	36.40955
Belowground								
0- 2mm Root	3304.8	49.24152		47.58912	33.66122	84.32197	18.71802	9.055152
2- 5mm Root	761.4	6.54804		6.463115	3.098078	6.119899	5.319258	1.02461
5-10mm Root	1085.4	9.44298		12.80772	15.54293	29.39806	3.554685	1.709505
10-20mm Root	1031.4			6.059475	1.145885	1.871991	4.202955	0.77716
20-50mm Root	1787.4							

Tissue	V (kg/ha)	OO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
<b>Aboveground</b>								
<b>Salix</b>								
New Leaves	5.13E-05	6.27E-05	2.59E-05	0.000152	3.27E-05	0.015297	0.00545	0.000497
New Twigs	5.83E-05	2.64E-05	1.04E-05	1.34E-05	5.94E-06	0.007341	0.004233	0.000256
New Wood	0.000123	0.00011	0.000146	1.66E-05	4.27E-05	0.010862	0.009788	0.000962
Reproductive	2.26E-06	9.37E-06	8.85E-07	2.83E-06	3.71E-07	0.000297	0.000159	4.42E-05
Old Twigs	0.001416	0.001573	0.001448	0.000321	0.000423	0.151515	0.150036	0.017944
Dead Wood	0.007987	0.002088	0.00137	5.42E-05	0.000353	0.197305	0.197034	0.0024
Shrubs	0.000609	0.000321	0.000755	0.000364	0.000285	0.046888	0.106706	0.000184
Live Herbs	2.33E-05	2.25E-06	0.000236	0.000918	0.000197	0.012925	0.018147	1.91E-05
Litter	0.019505	0.08178	0.002291	0.005441	0.002046	0.274122	0.17442	0.365844
<b>Belowground</b>								
0- 2mm Root	0.012454	0.006971	0.021433	0.025486	0.010932	0.131195	0.441613	0.028146
2- 5mm Root	0.001305	0.000815	0.002962	0.0031	0.001265	0.024256	0.088311	0.001349
5-10mm Root	0.002665	0.002556	0.006572	0.007099	0.002073	0.011836	0.082979	0.005167
10-20mm Root	0.000975	0.001238	0.002852	0.003115	0.001124	0.009484	0.067041	0
20-50mm Root								

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
<b>Aboveground</b>						
<b>Salix</b>						
New Leaves	0	0.000132	0.002981	0	1.82E-05	0
New Twigs	0	0.000183	0.00165	3.71E-06	0	3.71E-07
New Wood	0	0.000442	0.00354	1.34E-05	0	0
Reproductive	2.86E-08	1.71E-05	0.000154	2.86E-07	3.54E-06	0
Old Twigs	0	0.006847	0.050865	0.000203	0	0
Dead Wood	0	0.002576	0.037766	0	0	0
Shrubs	0	0.000846	0.011722	0	0.001699	4.04E-07
Live Herbs	0.000124	0.000154	0.002725	9.61E-05	0.000568	5.15E-05
Litter	0	0.005376	0.026998	0	0	0
<b>Belowground</b>						
0- 2mm Root	2.94E-05	0.004274	0.076042	0	0.087208	0.000709
2- 5mm Root	0.000122	0.000982	0.00578	0	0.008167	0.000238
5-10mm Root	0	0.001612	0.008358	0	0.015521	0.000304
10-20mm Root	0.000444	0.00149	0.004033	0	0.007117	0.000392
20-50mm Root						

Table 23. Emerald Lake Mesic Shrubs: Biomass and mineral capitals, community basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
New Leaves	744.51	11.0932	0.897135	1.265667	0.036816	6.462347	3.952107	1.186253
New Twigs	215.7	2.26485	0.210308	0.355905	0.034019	1.963949	1.169094	0.25884
Reproductive	26.52	0.307632	0.032089	0.037128	0.000934	0.200668	0.130478	0.03094
Old Leaves	727.32	7.63686	0.741866	0.581856	0.345986	6.612551	3.738425	1.147953
Old Twigs	2052.66	11.4949	1.344492	0.923697	0.056688	10.84489	7.218521	1.434467
Dead Wood	613.8	3.92832	0.626076	0.18414	0.0338	2.391774	3.60096	0.526231
Litter	4855.44	65.10179		4.360295	0.629321	14.51166	13.82997	5.077687
0- 2mm Roots	3441	51.2709		49.5504	35.0485	87.79711	19.48944	9.42834
2- 5mm Roots	1323	11.3778		11.23023	5.383185	10.63387	9.242682	1.780351
5-10mm Roots	1347	11.7189		15.8946	19.28904	36.4835	4.411425	2.121525
10-20mm Roots	822			4.82925	0.913242	1.49193	3.34965	0.619377
20-50mm Roots	54							

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
New Leaves	0	0.0005	0.00565	0	0.000669	0
New Twigs	0	0.000118	0.001729	0	0.000352	0
Reproductive	0	1.67E-05	0.000238	0	1.3E-05	0
Old Leaves	0	0.000273	0.00751	0	0.002112	1.21E-06
Old Twigs	0	0.001307	0.014314	0	0.000961	0
Dead Wood	0	0.000323	0.005727	0	0.00099	0
Litter	0	0.005866	0.014756	0	0	0
0- 2mm Roots	3.06E-05	0.00445	0.079175	0	0.090802	0.000738
2- 5mm Roots	0.000212	0.001706	0.010044	0	0.014191	0.000413
5-10mm Roots	0	0.002	0.010372	0	0.019262	0.000377
10-20mm Roots	0.000353	0.001188	0.003214	0	0.005672	0.000312
20-50mm Roots						

Table 24. Emerald Lake Mesic Rock Crevices: Biomass and mineral capital, community basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
Live Shoot	292.034	2.448384	0.256798	0.223226	0.033883	1.898412	1.320639	0.305646
Litter	323.696	4.340119			0.290686	0.041955	0.967444	0.921998
Roots	465.8	5.668537			5.475954	4.073749	9.16459	2.451829

Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
Live Shoot	0.005303	0.001865	0.114143	0.12601	0.004948	0.136347	1.010337	0.00484
Litter	0.02995	0.002699	1.021669	0.169265	0.003474	0.548657	1.630433	0.014756
Roots	0.018255	0.013532	1.206519	0.714843	0.004251	3.86494	7.542937	0.194922

Tissue	V (kg/ha)	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
Live Shoot	0.000122	6.43E-05	0.000151	7.27E-05	5.7E-05	0.009378	0.021341	3.68E-05
Litter	0.000317	0.00305	0.000207	0.00011	0.00011	0.006976	0.025208	0.001474
Roots	0.001298	0.000862	0.002546	0.002903	0.001145	0.013504	0.051711	0.002557

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
Live Shoot	0	0.000169	0.002344		0	0.00034
Litter	0	0.000391	0.000984		0	0
Roots	4E-05	0.000628	0.006907		0	0.008729
						0.000124

Table 25. Emerald Lake Wet Meadow Herbs: Biomass and mineral captials, community basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)	ZN (kg/ha)
Live Shoots	3770	64.14141	6.066273	1.458148	80.99722	34.38015	8.788853	0.08076
Litter	1370	20.9747	1.1645	1.388858	10.13487	6.703804	2.096245	0.108689
Roots	28970	254.936	338.8331	204.7793	385.7645	87.27695	51.89493	2.348501

Tissue	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)	V (kg/ha)
Live Shoots	0.040493	1.537709	1.859202	0.228322	2.873107	21.80693	0.142436	0.000333
Litter	0.021938	4.128848	1.451889	0.036247	5.112217	15.88141	0.261975	0.002034
Roots	3.521979	80.36278	12.65216	0.167234	221.2922	471.8247	9.477053	0.079571

Tissue	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)	AG (kg/ha)
Live Shoots	3.22E-05	0.003374	0.013117	0.002817	0.184648	0.259239	0.000273	0.001776
Litter	0.000674	0.004797	0.00756	0.002833	0.053168	0.133307	0.003231	0.000222
Roots	0.022519	0.084264	0.160706	0.079803	1.107272	2.193029	0.111225	0.003206

Tissue	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
Live Shoots	0.002205	0.038927	0.001373	0.008118	0.000735
Litter	0.001441	0.005665	0.000104	0	0.00033
Roots	0.037371	0.41485		0.844224	0.007146

Table 26. Emerald Lake Xeric Rock Crevices: Biomass and mineral capitals, community basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
<b>Aboveground</b>								
Shrubs	28.9	0.242295	0.025413	0.022091	0.003353	0.187869	0.130692	0.030247
Live Herbs	24.8			0.047695	0.006142	0.481221	0.262609	0.062497
Litter	436.2	3.290863		0.309637	0.2079	1.945376	1.768446	0.510561
Roots	295.2	3.16848		2.993583	2.190788	4.609009	1.476003	0.473367

Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
<b>Aboveground</b>								
Shrubs	0.000525	0.000185	0.011296	0.01247	0.00049	0.013493	0.099984	0.000479
Live Herbs	0.000568	0.000109	0.007439	0.007829	0.000692	0.010934	0.112617	0.000868
Litter	0.033155	0.00351	1.113245	0.350186	0.004273	0.969429	3.497008	0.056929
Roots	0.010041	0.007331	0.70005	0.406506	0.002739	1.855983	4.281119	0.092534

Tissue	V (kg/ha)	OO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
<b>Aboveground</b>								
Shrubs	1.21E-05	6.36E-06	1.49E-05	7.2E-06	5.64E-06	0.000928	0.002112	3.64E-06
Live Herbs	1E-05	0	1.59E-05	6.1E-05	1.07E-05	0.003853	0.001879	1.53E-06
Litter	0.003012	0.00277	0.000987	0.000937	0.000378	0.032398	0.045936	0.001333
Roots	0.000656	0.000497	0.001417	0.001575	0.000588	0.006764	0.02886	0.001111

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
<b>Aboveground</b>						
Shrubs	0	1.67E-05	0.000232		3.36E-05	8E-09
Live Herbs	1.22E-05	1.69E-05	0.000345		4.23E-05	1.19E-05
Litter	3.69E-05	0.000494	0.001917		0	0.00013
Roots	4.42E-05	0.000407	0.003115		0	0

Table 27. Emerald Lake Dry Meadows: Biomass and mineral capitals, community basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
Live Herbs	976.6			1.878179	0.241864	18.95004	10.34131	2.461076
Litter	771.4			0.783679	0.500739	5.153967	4.383012	1.275906
Roots	5608.8	60.20112		56.87809	41.62498	87.57117	28.04406	8.99398

Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
Live Herbs	0.022351	0.004305	0.292936	0.308286	0.027245	0.430579	4.434741	0.03418
Litter	0.065385	0.00507	1.709663	0.523292	0.009401	1.665304	7.020153	0.136646
Roots	0.190785	0.139289	13.30095	7.723605	0.052045	35.26368	81.34126	1.758144

Tissue	V (kg/ha)	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
Live Herbs	0.000395	0	0.000625	0.002403	0.000422	0.151724	0.073991	6.04E-05
Litter	0.005244	0	0.001933	0.00301	0.000922	0.094961	0.082702	0.001551
Roots	0.012455	0.009443	0.026917	0.029927	0.011173	0.12852	0.548348	0.021101

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
Live Herbs	0.000481	0.000664	0.013596		0.001666	0.00047
Litter	0.000131	0.000943	0.004301		0	0.000459
Roots	0.00084	0.00773	0.059188			

Table 28. Emerald Lake Fell Field: Biomass and mineral capital, community basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
Live Herbs	51.4			0.098852	0.01273	0.99737	0.544279	0.12953
Litter	40.6			0.041246	0.026355	0.271261	0.230685	0.067153
Roots	295.2	3.16848		2.993583	2.190788	4.609009	1.476003	0.473367

Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
Live Herbs	0.001176	0.000227	0.015418	0.016226	0.001434	0.022662	0.233407	0.001799
Litter	0.003441	0.000267	0.089982	0.027542	0.000495	0.087648	0.369482	0.007192
Roots	0.010041	0.007331	0.70005	0.406506	0.002739	1.855983	4.281119	0.092534

Tissue	V (kg/ha)	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	EA (kg/ha)	LI (kg/ha)
Live Herbs	2.08E-05	0	3.29E-05	0.000126	2.22E-05	0.007985	0.003894	3.18E-06
Litter	0.000276	0	0.000102	0.000158	4.85E-05	0.004998	0.004353	8.16E-05
Roots	0.000656	0.000497	0.001417	0.001575	0.000588	0.006764	0.02886	0.001111

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
Live Herbs	2.53E-05	3.5E-05	0.000716		8.77E-05	2.47E-05
Litter	6.88E-06	4.97E-05	0.000226		0	2.41E-05
Roots	4.42E-05	0.000407	0.003115			

Table 29. Emerald Lake Colluvium: Biomass and mineral capitals, community basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
Live Herbs	51.4			0.098852	0.01273	0.99737	0.544279	0.12953
Litter	40.6			0.041246	0.026355	0.271261	0.230685	0.067153
Roots	295.2	3.16848		2.993583	2.190788	4.609009	1.476003	0.473367

Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
Live Herbs	0.001176	0.000227	0.015418	0.016226	0.001434	0.022662	0.233407	0.001799
Litter	0.003441	0.000267	0.089982	0.027542	0.000495	0.087648	0.369482	0.007192
Roots	0.010041	0.007331	0.70005	0.406506	0.002739	1.855983	4.281119	0.092534

Tissue	V (kg/ha)	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
Live Herbs	2.08E-05	0	3.29E-05	0.000126	2.22E-05	0.007985	0.003894	3.18E-06
Litter	0.000276	0	0.000102	0.000158	4.85E-05	0.004998	0.004353	8.16E-05
Roots	0.000656	0.000497	0.001417	0.001575	0.000588	0.006764	0.02886	0.001111

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
Live Herbs	2.53E-05	3.5E-05	0.000716		8.77E-05	2.47E-05
Litter	6.88E-06	4.97E-05	0.000226		0	2.41E-05
Roots	4.42E-05	0.000407	0.003115			

Table 30. Emerald Lake Willows  
community basis.

## Productivity and mineral fluxes.

Tissue	Product.	N	S	P	NA	K	CA	MG
		kg/ha/yr						
Aboveground								
Salix	New Leaves	22.21038	0.626333	0.042533	0.0422	0.001028	0.193675	0.244536
	New Twigs	18.15853	0.24514	0.017795	0.029054	0.000335	0.097269	0.074299
	New Wood	38.65252	0.239646	0.023965	0.034787	0.000919	0.069362	0.147182
	Reproductive	1.396584	0.023602	0.001788	0.003771	9.44E-05	0.010281	0.003108
	Old Twigs	573.9931	3.654423	0.369269	0.459194	0.01295	0.910608	1.960314
	Dead Wood	331.5537	1.724079	0.311661	0.066311	0.005499	0.696263	2.576173
Shrubs		451.4846	3.785201	0.397009	0.345108	0.052383	2.934944	2.041708
Live Herbs		237.7211	4.044501		0.382515	0.091945	5.107361	2.167874
Litter		-1433.96	-36.3885		-1.43923	-0.17402	-4.30549	-8.47147
Belowground								
0- 2mm Root		-2302	-34.2998		-33.1488	-23.4471	-58.7355	-13.0383
2- 5mm Root		441	3.7926		3.743412	1.794395	3.544622	3.080894
5-10mm Root		2684	23.3508		31.6712	38.43488	72.69614	8.7901
10-20mm Root		1639			9.629125	1.820929	2.974785	6.678925
20-50mm Root		3342						1.234986

Tissue	V	CO	NI	MO	CR	SR	BA	LI
	kg/ha/yr							
Aboveground								
Salix								
New Leaves	4.18E-06	5.11E-06	2.11E-06	1.24E-05	2.67E-06	0.001247	0.000444	4.05E-05
New Twigs	4.75E-06	2.15E-06	8.47E-07	1.09E-06	4.84E-07	0.000598	0.000345	2.09E-05
New Wood	9.99E-06	8.95E-06	1.19E-05	1.35E-06	3.48E-06	0.000885	0.000798	7.84E-05
Reproductive	1.84E-07	7.63E-07	7.22E-08	2.3E-07	3.03E-08	2.42E-05	1.3E-05	3.6E-06
Old Twigs	0.000115	0.000128	0.000118	2.61E-05	3.44E-05	0.012349	0.012228	0.001462
Dead Wood	0.000651	0.00017	0.000112	4.42E-06	2.87E-05	0.01608	0.016058	0.000196
Shrubs	0.000188	9.94E-05	0.000233	0.000112	8.81E-05	0.014498	0.032994	5.69E-05
Live Herbs	2.1E-05	2.03E-06	0.000213	0.000827	0.000178	0.011643	0.016347	1.72E-05
Litter	-0.00454	-0.01903	-0.00053	-0.00127	-0.00048	-0.06378	-0.04058	-0.08512
Belowground								
0- 2mm Root	-0.00867	-0.00486	-0.01493	-0.01775	-0.00761	-0.09139	-0.30761	-0.01961
2- 5mm Root	0.000756	0.000472	0.001716	0.001796	0.000732	0.014049	0.051149	0.000781
5-10mm Root	0.006589	0.006321	0.016252	0.017553	0.005126	0.029269	0.205192	0.012776
10-20mm Root	0.001549	0.001967	0.004532	0.00495	0.001787	0.015071	0.106535	0
20-50mm Root								

Tissue	AG	SN	PB	BE	CD	AS	
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	
Aboveground							
Salix							
New Leaves	0	1.08E-05	0.000243		0	1.48E-06	0
New Twigs	0	1.5E-05	0.000134	3.03E-07	0	3.03E-08	
New Wood	0	3.6E-05	0.000289	1.1E-06	0	0	
Reproductive	2.33E-09	1.39E-06	1.26E-05	2.33E-08	2.89E-07	0	
Old Twigs	0	0.000558	0.004146	1.66E-05	0	0	
Dead Wood	0	0.00021	0.003078		0	0	0
Shrubs	0	0.000262	0.003625		0.000525	1.25E-07	
Live Herbs	0.000112	0.000139	0.002455	8.66E-05	0.000512	4.64E-05	
Litter	0	-0.00125	-0.00628		0	0	0
Belowground							
0- 2mm Root	-2E-05	-0.00298	-0.05297		-0.06075	-0.00049	
2- 5mm Root	7.06E-05	0.000569	0.003348		0.00473	0.000138	
5-10mm Root	0	0.003986	0.020667		0.038381	0.000752	
10-20mm Root	0.000705	0.002368	0.006408		0.011309	0.000623	
20-50mm Root							

Table 31 . Emerald Lake Mesic Shrubs: Productivity and mineral fluxes, community basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
New Leaves	230.2025	3.430017	0.277394	0.391344	0.011384	1.998158	1.221992	0.366789
New Twigs	66.69444	0.700292	0.065027	0.110046	0.010519	0.607253	0.361484	0.080033
Reproductive	8.199984	0.09512	0.009922	0.01148	0.000289	0.062047	0.040344	0.009567
Old Leaves	224.8873	2.361317	0.229385	0.17991	0.106979	2.044601	1.155921	0.354947
Old Twigs	634.6825	3.554222	0.415717	0.285607	0.017528	3.353239	2.231967	0.443537
Dead Wood	189.787	1.214637	0.193583	0.056936	0.010451	0.739537	1.113417	0.162711
Litter	-1501.3	-20.1295		-1.3482	-0.19459	-4.487	-4.27623	-1.57002
0- 2mm Roots	-2244.3	-33.4401		-32.3179	-22.8594	-57.2633	-12.7115	-6.14938
2- 5mm Roots	-615.9	-5.29674		-5.22804	-2.50605	-4.95041	-4.30277	-0.82881
5-10mm Roots	-1249.2	-10.868		-14.7406	-17.8885	-33.8346	-4.09113	-1.96749
10-20mm Roots	-652.5			-3.83344	-0.72493	-1.18429	-2.65894	-0.49166
20-50mm Roots	153.3							

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
New Leaves	0	0.000155	0.001747	0	0.000207	0
New Twigs	0	3.66E-05	0.000535	0	0.000109	0
Reproductive	0	5.17E-06	7.35E-05	0	4.02E-06	0
Old Leaves	0	8.43E-05	0.002322	0	0.000653	3.75E-07
Old Twigs	0	0.000404	0.004426	0	0.000297	0
Dead Wood	0	1E-04	0.001771	0	0.000306	0
Litter	0	-0.00181	-0.00456	0	0	0
0- 2mm Roots	-2E-05	-0.0029	-0.05164	0	-0.05922	-0.00048
2- 5mm Roots	-9.9E-05	-0.0079	-0.00468	0	-0.00661	-0.00019
5-10mm Roots	0	-0.00186	-0.00962	0	-0.01786	-0.00035
10-20mm Roots	-0.00028	-0.00094	-0.00255	0	-0.0045	-0.00025
20-50mm Roots						

Table 32. Emerald Lake Mesic Rock Crevices: Productivity and mineral fluxes, community basis.

Tissue	Biomass	N	S	P	NA	K	CA	MG
	kg/ha/yr							
Live Shoot	90.29691	0.75704	0.079402	0.069022	0.010477	0.586989	0.408342	0.094506
Litter	-100.087	-1.34196			-0.08988	-0.01297	-0.29913	-0.28508
Roots	-307.24	-1.28644			-1.35333	-1.05933	-2.44446	-0.53234

Tissue	ZN	CU	FE	MN	B	AL	SI	TI
	kg/ha/yr							
Live Shoot	0.00164	0.000577	0.035293	0.038962	0.00153	0.042159	0.312396	0.001496
Litter	-0.00926	-0.00083	-0.3159	-0.05234	-0.00107	-0.16964	-0.50413	-0.00456
Roots	-0.00404	-0.00329	-0.28874	-0.17371	-0.00093	-1.0042	-1.8333	-0.05119

Tissue	V	CO	NI	MO	CR	SR	BA	LI
	kg/ha/yr							
Live Shoot	3.77E-05	1.99E-05	4.67E-05	2.25E-05	1.76E-05	0.0029	0.006599	1.14E-05
Litter	-9.8E-05	-0.00094	-6.4E-05	-3.4E-05	-3.4E-05	-0.00216	-0.00779	-0.00046
Roots	-0.00033	-0.00021	-0.00063	-0.00073	-0.00029	-0.00326	-0.0121	-0.00071

Tissue	AG	SN	PB	BE	CD	AS	
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	
Live Shoot	0	5.23E-05	0.000725		0	0.000105	2.5E-08
Litter	0	-0.00012	-0.0003		0	0	0
Roots	-4E-06	-0.00014	-0.00185		0	-0.00227	-2.5E-05

Table 33. Emerald Lake Wet Meadow Herbs: Productivity and mineral fluxes, community basis.

Tissue	Product.	N kg/ha/yr	P kg/ha/yr	NA kg/ha/yr	K kg/ha/yr	CA kg/ha/yr	MG kg/ha/yr	ZN kg/ha/yr
--------	----------	---------------	---------------	----------------	---------------	----------------	----------------	----------------

Live Shoots	3180	54.10336	5.116909	1.22995	68.32126	28.9997	7.41341	0.068121
Litter	-1370	-20.9747	-1.1645	-1.38886	-10.1349	-6.7038	-2.09625	-0.10869
Roots	-9111	-80.1768	-106.562	-64.4026	-121.322	-27.4484	-16.3208	-0.7386

Tissue	CU kg/ha/yr	FE kg/ha/yr	MN kg/ha/yr	B kg/ha/yr	AL kg/ha/yr	SI kg/ha/yr	TI kg/ha/yr	V kg/ha/yr
--------	----------------	----------------	----------------	---------------	----------------	----------------	----------------	---------------

Live Shoots	0.034156	1.29706	1.568239	0.19259	2.423469	18.39417	0.120145	0.000281
Litter	-0.02194	-4.12885	-1.45189	-0.03625	-5.11222	-15.8814	-0.26198	-0.00203
Roots	-1.10765	-25.2739	-3.97908	-0.05259	-69.5959	-148.388	-2.98051	-0.02502

Tissue	CO kg/ha/yr	NI kg/ha/yr	MO kg/ha/yr	CR kg/ha/yr	SR kg/ha/yr	BA kg/ha/yr	LI kg/ha/yr	AG kg/ha/yr
--------	----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------

Live Shoots	2.71E-05	0.002846	0.011064	0.002377	0.155751	0.218669	0.000231	0.001498
Litter	-0.00067	-0.0048	-0.00756	-0.00283	-0.05317	-0.13331	-0.00323	-0.00022
Roots	-0.00708	-0.0265	-0.05054	-0.0251	-0.34823	-0.6897	-0.03498	-0.00101

Tissue	SN kg/ha/yr	PB kg/ha/yr	BE kg/ha/yr	CD kg/ha/yr	AS kg/ha/yr
--------	----------------	----------------	----------------	----------------	----------------

Live Shoots	0.00186	0.032835	0.001158	0.006848	0.00062
Litter	-0.00144	-0.00567	-0.0001	0	-0.00033
Roots	-0.01175	-0.13047		-0.26551	-0.00225

Table 34. Emerald Lake Xeric Rock Crevices: Productivity and mineral fluxes, community basis.

Tissue	Product.	N kg/ha/yr	S kg/ha/yr	P kg/ha/yr	NA kg/ha/yr	K kg/ha/yr	CA kg/ha/yr	MG kg/ha/yr
--------	----------	---------------	---------------	---------------	----------------	---------------	----------------	----------------

Aboveground

Shrubs	8.93588	0.074918	0.007858	0.00683	0.001037	0.058089	0.04041	0.009352
Live Herbs	22.33984			0.042964	0.005533	0.433484	0.236559	0.056297
Litter	-254.05	-1.91665		-0.18034	-0.12108	-1.13302	-1.02997	-0.29736
Roots	-89.4486	-0.96008		-0.90709	-0.66383	-1.39658	-0.44724	-0.14344

Tissue	ZN kg/ha/yr	CU kg/ha/yr	FE kg/ha/yr	MN kg/ha/yr	B kg/ha/yr	AL kg/ha/yr	SI kg/ha/yr	TI kg/ha/yr
--------	----------------	----------------	----------------	----------------	---------------	----------------	----------------	----------------

Aboveground

Shrubs	0.000162	5.71E-05	0.003493	0.003856	0.000151	0.004172	0.030915	0.000148
Live Herbs	0.000511	9.85E-05	0.006701	0.007052	0.000623	0.00985	0.101445	0.000782
Litter	-0.01931	-0.00204	-0.64837	-0.20395	-0.00249	-0.56461	-2.03671	-0.03316
Roots	-0.00304	-0.00222	-0.21212	-0.12318	-0.00083	-0.56238	-1.29722	-0.02804

Tissue	V kg/ha/yr	CO kg/ha/yr	NI kg/ha/yr	MO kg/ha/yr	CR kg/ha/yr	SR kg/ha/yr	BA kg/ha/yr	LI kg/ha/yr
--------	---------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------

Aboveground

Shrubs	3.73E-06	1.97E-06	4.62E-06	2.23E-06	1.74E-06	0.000287	0.000653	1.13E-06
Live Herbs	9.04E-06		0	1.43E-05	5.5E-05	9.65E-06	0.003471	0.001693
Litter	-0.00175	-0.00161	-0.00058	-0.00055	-0.00022	-0.01887	-0.02675	-0.00078
Roots	-0.0002	-0.00015	-0.00043	-0.00048	-0.00018	-0.00205	-0.00874	-0.00034

Tissue	AG kg/ha/yr	SN kg/ha/yr	PB kg/ha/yr	BE kg/ha/yr	CD kg/ha/yr	AS kg/ha/yr
--------	----------------	----------------	----------------	----------------	----------------	----------------

Aboveground

Shrubs	0	5.18E-06	7.17E-05		0	1.04E-05	2.47E-09
Live Herbs	1.1E-05	1.52E-05	0.000311		3.81E-05	1.07E-05	
Litter	-2.2E-05	-0.00029	-0.00112		0	0	-7.6E-05
Roots	-1.3E-05	-0.00012	-0.00094				

Table 35. Emerald Lake Dry Meadows: Productivity and mineral fluxes, community basis.

Tissue	Product.	N kg/ha/yr	S kg/ha/yr	P kg/ha/yr	NA kg/ha/yr	K kg/ha/yr	CA kg/ha/yr	MG kg/ha/yr
--------	----------	---------------	---------------	---------------	----------------	---------------	----------------	----------------

Live Herbs	879.7213			1.691864	0.217871	17.07019	9.315449	2.216938
Litter	-694.877			-0.70594	-0.45107	-4.64269	-3.94822	-1.14934
Roots		-2516	-27.0051		-25.5144	-18.6722	-39.2828	-12.58

Tissue	ZN kg/ha/yr	CU kg/ha/yr	FE kg/ha/yr	MN kg/ha/yr	B kg/ha/yr	AL kg/ha/yr	SI kg/ha/yr	TI kg/ha/yr
--------	----------------	----------------	----------------	----------------	---------------	----------------	----------------	----------------

Live Herbs	0.020134	0.003878	0.263876	0.277704	0.024542	0.387865	3.994814	0.030789
Litter	-0.0589	-0.00457	-1.54006	-0.47138	-0.00847	-1.50011	-6.32375	-0.12309
Roots	-0.08558	-0.06248	-5.96656	-3.46466	-0.02335	-15.8186	-36.4882	-0.78867

Tissue	V kg/ha/yr	CO kg/ha/yr	NI kg/ha/yr	MO kg/ha/yr	CR kg/ha/yr	SR kg/ha/yr	BA kg/ha/yr	LI kg/ha/yr
--------	---------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------

Live Herbs	0.000356	0	0.000563	0.002165	0.00038	0.136673	0.066651	5.44E-05
Litter	-0.00472	0	-0.00174	-0.00271	-0.00083	-0.08554	-0.0745	-0.0014
Roots	-0.00559	-0.00424	-0.01207	-0.01342	-0.00501	-0.05765	-0.24598	-0.00947

Tissue	AG kg/ha/yr	SN kg/ha/yr	PB kg/ha/yr	BE kg/ha/yr	CD kg/ha/yr	AS kg/ha/yr
--------	----------------	----------------	----------------	----------------	----------------	----------------

Live Herbs	0.000433	0.000598	0.012248		0.001501	0.000423
Litter	-0.00012	-0.00085	-0.00387		0	-0.00041
Roots	-0.00038	-0.00347	-0.02655			

Table 36 . Emerald Lake Fell Fields: Productivity and mineral fluxes, community basis.

Tissue	Biomass	N	S	P	NA	K	CA	MG
	kg/ha/yr							

Live Herbs	46.30112			0.089045	0.011467	0.898431	0.490287	0.116681
Litter	-36.5725			-0.03715	-0.02374	-0.24435	-0.2078	-0.06049
Roots	-132.421	-1.42132		-1.34287	-0.98275	-2.06752	-0.66211	-0.21234

Tissue	ZN	CU	FE	MN	B	AL	SI	TI
	kg/ha/yr							

Live Herbs	0.00106	0.000204	0.013888	0.014616	0.001292	0.020414	0.210253	0.00162
Litter	-0.0031	-0.00024	-0.08106	-0.02481	-0.00045	-0.07895	-0.33283	-0.00648
Roots	-0.0045	-0.00329	-0.31403	-0.18235	-0.00123	-0.83256	-1.92043	-0.04151

Tissue	V	CO	NI	MO	CR	SR	BA	LI
	kg/ha/yr							

Live Herbs	1.87E-05	0	2.97E-05	0.000114	2E-05	0.007193	0.003508	2.86E-06
Litter	-0.00025	0	-9.2E-05	-0.00014	-4.4E-05	-0.0045	-0.00392	-7.4E-05
Roots	-0.00029	-0.00022	-0.00064	-0.00071	-0.00026	-0.00303	-0.01295	-0.0005

Tissue	AG	SN	PB	BE	CD	AS
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr

Live Herbs	2.28E-05	3.15E-05	0.000645		7.9E-05	2.23E-05
Litter	-6.2E-06	-4.5E-05	-0.0002		0	-2.2E-05
Roots	-2E-05	-0.00018	-0.0014			

Table 37. Emerald Lake Colluvium: Productivity and mineral fluxes, community basis.

Tissue	Product.	N kg/ha/yr	S kg/ha/yr	P kg/ha/yr	NA kg/ha/yr	K kg/ha/yr	CA kg/ha/yr	MG kg/ha/yr
--------	----------	---------------	---------------	---------------	----------------	---------------	----------------	----------------

Live Herbs	46.30112			0.089045	0.011467	0.898431	0.490287	0.116681
Litter	-36.5725			-0.03715	-0.02374	-0.24435	-0.2078	-0.06049
Roots	-132.421	-1.42132		-1.34287	-0.98275	-2.06752	-0.66211	-0.21234

Tissue	ZN kg/ha/yr	CU kg/ha/yr	FE kg/ha/yr	MN kg/ha/yr	B kg/ha/yr	AL kg/ha/yr	SI kg/ha/yr	TI kg/ha/yr
--------	----------------	----------------	----------------	----------------	---------------	----------------	----------------	----------------

Live Herbs	0.00106	0.000204	0.013888	0.014616	0.001292	0.020414	0.210253	0.00162
Litter	-0.0031	-0.00024	-0.08106	-0.02481	-0.00045	-0.07895	-0.33283	-0.00648
Roots	-0.0045	-0.00329	-0.31403	-0.18235	-0.00123	-0.83256	-1.92043	-0.04151

Tissue	V kg/ha/yr	CO kg/ha/yr	NI kg/ha/yr	MO kg/ha/yr	CR kg/ha/yr	SR kg/ha/yr	BA kg/ha/yr	LI kg/ha/yr
--------	---------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------

Live Herbs	1.87E-05	0	2.97E-05	0.000114	2E-05	0.007193	0.003508	2.86E-06
Litter	-0.00025	0	-9.2E-05	-0.00014	-4.4E-05	-0.0045	-0.00392	-7.4E-05
Roots	-0.00029	-0.00022	-0.00064	-0.00071	-0.00026	-0.00303	-0.01295	-0.0005

Tissue	AG kg/ha/yr	SN kg/ha/yr	PB kg/ha/yr	BE kg/ha/yr	CD kg/ha/yr	AS kg/ha/yr
--------	----------------	----------------	----------------	----------------	----------------	----------------

Live Herbs	2.28E-05	3.15E-05	0.000645		7.9E-05	2.23E-05
Litter	-6.2E-06	-4.5E-05	-0.0002		0	-2.2E-05
Roots	-2E-05	-0.00018	-0.0014			

Table 38. Emerald Lake Trees: Biomass and mineral capitals, whole-watershed basis

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	Na (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
Needles	381.7096	4.163179	0.33056	0.358807	0.023901	1.531762	1.121936	0.420804
Live Br.	6118.077	37.34066	4.538594	4.884265	0.47898	36.82781	10.68437	7.221628
Stem Wood	7862.328	37.73917	4.442215	5.110513	0.431773	43.12487	5.47087	6.946366
Stem Bark	1683.145	12.4665	1.54625	1.593378	0.171112	11.03136	4.70757	2.486428
Litter	37.66905	1.618004	0.128471	0.139449	0.009289	0.595314	0.436036	0.163544
Fine Roots	1300.967	6.049497		8.23223	2.9743	10.48435	1.619415	1.801406
Woody Roots	4336.557	16.47892		18.67085	10.80256	24.80116	7.66309	5.415965
Tissue	Zn (kg/ha)	Cu (kg/ha)	Fe (kg/ha)	Mn (kg/ha)	B (kg/ha)	Al (kg/ha)	Si (kg/ha)	Ti (kg/ha)
Needles	0.007623	0.002899	0.056776	0.104152	0.011549	0.136906	0.140562	0.001001
Live Br.	0.173112	0.052219	0.760356	0.723573	0.208852	1.387463	3.062008	0.019206
Stem Wood	0.17402	0.056124	0.504368	0.858959	0.275837	0.932734	1.3687	0.004744
Stem Bark	0.057996	0.016717	0.310389	0.214241	0.055864	0.563733	1.391772	0.009552
Litter	0.002963	0.001127	0.022066	0.040478	0.004488	0.053208	0.054629	0.000389
Fine Roots	0.008534	0.017881	2.152378	0.754127	0.015205	8.394128	17.74519	0.187975
Woody Roots	0.023398	0.037925	4.34523	2.478539	0.037637	13.24463	48.64828	0.2835
Tissue	V (kg/ha)	Co (kg/ha)	Ni (kg/ha)	Mo (kg/ha)	Cr (kg/ha)	Sr (kg/ha)	Ba (kg/ha)	Li (kg/ha)
Needles	0.000799	0.000436	0.000607	0.000141	3.39E-05	0.004965	0.001998	0.000257
Live Br.	0.011779	0.003193	0.00419	0.001484	0.000177	0.069401	0.036216	0.003176
Stem Wood	0.015004	0	0.001979	0.000773	0	0.042181	0.015777	0.003433
Stem Bark	0.003269	0.001757	0.001882	0.000651	9.74E-05	0.029156	0.016549	0.001012
Litter	0.000311	0.000169	0.000236	5.48E-05	1.32E-05	0.00193	0.000776	0.0001
Fine Roots	8.38E-05	0.00108	0.002657	0.003881	0.001889	0.00913	0.081643	0.000929
Woody Roots	0.000185	0.000461	0.005634	0.008823	0.005503	0.030443	0.208013	0.001802
Tissue	Ag (kg/ha)	Sn (kg/ha)	Pb (kg/ha)	Be (kg/ha)	Cd (kg/ha)	As (kg/ha)		
Needles	0	0.000442	0.008251	2.47E-06	3.11E-05	1.01E-05		
Live Br.	0	0.006997	0.097639	7.14E-05	0.001007	0.000143		
Stem Wood	0	0.008491	0.070014	1.31E-05	0.000917	0.000105		
Stem Bark	0	0.002032	0.038735	3.65E-05	0.000358	5.6E-05		
Litter	0	0.000172	0.003207	9.61E-07	1.21E-05	3.93E-06		
Fine Roots	0.000559	0.001899	0.00356		0.000162	0.000416		
Woody Roots	0.00304	0.005795	0.018257		0	0.001396		

Table 39. Emerald Lake Willows watershed basis.

## Biomass and mineral capitals, whole-

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
<b>Aboveground</b>								
<b>Salix</b>								
New Leaves	19.41705	0.547561	0.037184	0.036892	0.000899	0.169317	0.213782	0.039222
New Twigs	15.87479	0.21431	0.015557	0.0254	0.000293	0.085036	0.064954	0.018507
New Wood	33.79131	0.209506	0.020951	0.030412	0.000803	0.060639	0.128672	0.018292
Reproductive	1.22094	0.020634	0.001563	0.003297	8.25E-05	0.008988	0.002717	0.001245
Old Twigs	501.8038	3.194817	0.322827	0.401443	0.011321	0.796084	1.713771	0.26038
Dead Wood	289.8553	1.507247	0.272464	0.057971	0.004808	0.608696	2.252175	0.225797
Shrubs	104.0371	0.872237	0.091484	0.079524	0.012071	0.676309	0.470478	0.108886
Live Herbs	18.80288	0.319905		0.030256	0.007273	0.403974	0.171471	0.043834
Litter	439.1152	11.14309		0.440728	0.053289	1.31845	2.59418	0.582184
<b>Belowground</b>								
0- 2mm Root	235.467	3.508458		3.390725	2.398362	6.007941	1.333659	0.64518
2- 5mm Root	54.24975	0.466548		0.460497	0.220738	0.436043	0.378997	0.073003
5-10mm Root	77.33475	0.672812		0.91255	1.107434	2.094612	0.253271	0.121802
10-20mm Root	73.48725			0.431738	0.081644	0.133379	0.299461	0.055373
20-50mm Root	127.3523							

Tissue	V (kg/ha)	OO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
<b>Aboveground</b>								
<b>Salix</b>								
New Leaves	3.66E-06	4.47E-06	1.84E-06	1.08E-05	2.33E-06	0.00109	0.000388	3.54E-05
New Twigs	4.15E-06	1.88E-06	7.41E-07	9.52E-07	4.23E-07	0.000523	0.000302	1.83E-05
New Wood	8.73E-06	7.83E-06	1.04E-05	1.18E-06	3.04E-06	0.000774	0.000697	6.85E-05
Reproductive	1.61E-07	6.67E-07	6.31E-08	2.01E-07	2.65E-08	2.11E-05	1.13E-05	3.15E-06
Old Twigs	0.000101	0.000112	0.000103	2.29E-05	3.01E-05	0.010795	0.01069	0.001278
Dead Wood	0.000569	0.000149	9.76E-05	3.86E-06	2.51E-05	0.014058	0.014039	0.000171
Shrubs	4.34E-05	2.29E-05	5.38E-05	2.59E-05	2.03E-05	0.003341	0.007603	1.31E-05
Live Herbs	1.66E-06	1.6E-07	1.68E-05	6.54E-05	1.41E-05	0.000921	0.001293	1.36E-06
Litter	0.00139	0.005827	0.000163	0.000388	0.000146	0.019531	0.012427	0.026066
<b>Belowground</b>								
0- 2mm Root	0.000887	0.000497	0.001527	0.001816	0.000779	0.009348	0.031465	0.002005
2- 5mm Root	9.3E-05	5.8E-05	0.000211	0.000221	9.01E-05	0.001728	0.006292	9.61E-05
5-10mm Root	0.00019	0.000182	0.000468	0.000506	0.000148	0.000843	0.005912	0.000368
10-20mm Root	6.94E-05	8.82E-05	0.000203	0.000222	8.01E-05	0.000676	0.004777	0
20-50mm Root								

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
<b>Aboveground</b>						
<b>Salix</b>						
New Leaves	0	9.42E-06	0.000212	0	1.29E-06	0
New Twigs	0	1.31E-05	0.000118	2.65E-07	0	2.65E-08
New Wood	0	3.15E-05	0.000252	9.57E-07	0	0
Reproductive	2.03E-09	1.22E-06	1.1E-05	2.03E-08	2.52E-07	0
Old Twigs	0	0.000488	0.003624	1.45E-05	0	0
Dead Wood	0	0.000184	0.002691	0	0	0
Shrubs	0	6.03E-05	0.000835	0.000121	2.88E-08	
Live Herbs	8.86E-06	1.1E-05	0.000194	6.85E-06	4.05E-05	3.67E-06
Litter	0	0.000383	0.001924		0	0
<b>Belowground</b>						
0- 2mm Root	2.09E-06	0.000305	0.005418		0.006214	5.05E-05
2- 5mm Root	8.68E-06	6.99E-05	0.000412		0.000582	1.69E-05
5-10mm Root	0	0.000115	0.000595		0.001106	2.17E-05
10-20mm Root	3.16E-05	0.000106	0.000287		0.000507	2.79E-05
20-50mm Root						

Table 40. Emerald Lake Mesic Shrubs: Biomass and mineral capitals, whole-watershed basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
New Leaves	4.529102	0.067484	0.005458	0.007699	0.000224	0.039313	0.024042	0.007216
New Twigs	1.312175	0.013778	0.001279	0.002165	0.000207	0.011947	0.007112	0.001575
Reproductive	0.16133	0.001871	0.000195	0.000226	5.68E-06	0.001221	0.000794	0.000188
Old Leaves	4.42453	0.046458	0.004513	0.00354	0.002105	0.040226	0.022742	0.006983
Old Twigs	12.48701	0.069927	0.008179	0.005619	0.000345	0.065973	0.043913	0.008726
Dead Wood	3.73395	0.023897	0.003809	0.00112	0.000206	0.01455	0.021906	0.003201
Litter	29.53726	0.396036		0.026525	0.003828	0.088279	0.084132	0.030889
0- 2mm Roots	20.93275	0.311898		0.301432	0.213212	0.534099	0.118561	0.057356
2- 5mm Roots	8.04825	0.069215		0.068317	0.032748	0.064689	0.056226	0.01083
5-10mm Roots	8.19425	0.07129		0.096692	0.117342	0.221941	0.026836	0.012906
10-20mm Roots	5.0005			0.029378	0.005556	0.009076	0.020377	0.003768
20-50mm Roots	0.3285							

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
New Leaves	0	3.04E-06	3.44E-05	0	4.07E-06	0
New Twigs	0	7.2E-07	1.05E-05	0	2.14E-06	0
Reproductive	0	1.02E-07	1.45E-06	0	7.91E-08	0
Old Leaves	0	1.66E-06	4.57E-05	0	1.28E-05	7.37E-09
Old Twigs	0	7.95E-06	8.71E-05	0	5.85E-06	0
Dead Wood	0	1.97E-06	3.48E-05	0	6.02E-06	0
Litter	0	3.57E-05	8.98E-05	0	0	0
0- 2mm Roots	1.86E-07	2.71E-05	0.000482	0	0.000552	4.49E-06
2- 5mm Roots	1.29E-06	1.04E-05	6.11E-05	0	8.63E-05	2.51E-06
5-10mm Roots	0	1.22E-05	6.31E-05	0	0.000117	2.29E-06
10-20mm Roots	2.15E-06	7.23E-06	1.96E-05	0	3.45E-05	1.9E-06
20-50mm Roots						

Table 41. Emerald Lake Mesic Rock Crevices: Biomass and mineral capitals, whole-watershed basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
Live Shoot	36.86929	0.309108	0.032421	0.028182	0.004278	0.239674	0.166731	0.038588
Litter	40.86662	0.54794		0	0.036699	0.005297	0.12214	0.116402
Roots	58.80725	0.715653		0	0.691339	0.514311	1.15703	0.309543

Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
Live Shoot	0.00067	0.000235	0.014411	0.015909	0.000625	0.017214	0.127555	0.000611
Litter	0.003781	0.000341	0.128986	0.02137	0.000439	0.069268	0.205842	0.001863
Roots	0.002305	0.001708	0.152323	0.090249	0.000537	0.487949	0.952296	0.024609

Tissue	V (kg/ha)	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
Live Shoot	1.54E-05	8.12E-06	1.91E-05	9.18E-06	7.19E-06	0.001184	0.002694	4.65E-06
Litter	4.01E-05	0.000385	2.61E-05	1.38E-05	1.39E-05	0.000881	0.003183	0.000186
Roots	0.000164	0.000109	0.000321	0.000367	0.000145	0.001705	0.006529	0.000323

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
Live Shoot	0	2.14E-05	0.000296	0	4.29E-05	1.02E-08
Litter	0	4.94E-05	0.000124	0	0	0
Roots	5.05E-06	7.93E-05	0.000872	0	0.001102	1.56E-05

Table 42. Emerald Lake Wet Meadow Herbs: Biomass and mineral capitals, whole-watershed basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)	ZN (kg/ha)
Live Shoots	130.065	2.212879	0.209286	0.050306	2.794404	1.186115	0.303215	0.002786
Litter	47.265	0.723627	0.040175	0.047916	0.349653	0.231281	0.07232	0.00375
Roots	999.465	8.795292	11.68974	7.064885	13.30888	3.011055	1.790375	0.081023

Tissue	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)	V (kg/ha)
Live Shoots	0.001397	0.053051	0.064142	0.007877	0.099122	0.752339	0.004914	1.15E-05
Litter	0.000757	0.142445	0.05009	0.001251	0.176371	0.547909	0.009038	7.02E-05
Roots	0.121508	2.772516	0.4365	0.00577	7.63458	16.27795	0.326958	0.002745

Tissue	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)	AG (kg/ha)
Live Shoots	1.11E-06	0.000116	0.000453	9.72E-05	0.00637	0.008944	9.43E-06	6.13E-05
Litter	2.33E-05	0.000165	0.000261	9.77E-05	0.001834	0.004599	0.000111	7.66E-06
Roots	0.000777	0.002907	0.005544	0.002753	0.038201	0.07566	0.003837	0.000111

Tissue	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
Live Shoots	7.61E-05	0.001343	4.74E-05	0.00028	2.54E-05
Litter	4.97E-05	0.000195	3.58E-06	0	1.14E-05
Roots	0.001289	0.014312		0.029126	0.000247

Table 43. Emerald Lake Xeric Rock Crevices: Biomass and mineral capitals, whole-watershed basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
<b>Aboveground</b>								
Shrubs	3.229575	0.027076	0.00284	0.002469	0.000375	0.020994	0.014605	0.00338
Live Herbs	2.7714			0.00533	0.000686	0.053776	0.029347	0.006984
Litter	48.74535	0.367754		0.034602	0.023233	0.217396	0.197624	0.057055
Roots	32.9886	0.354078		0.334533	0.244821	0.515057	0.164943	0.052899

Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
<b>Aboveground</b>								
Shrubs	5.87E-05	2.06E-05	0.001262	0.001394	5.47E-05	0.001508	0.011173	5.35E-05
Live Herbs	6.34E-05	1.22E-05	0.000831	0.000875	7.73E-05	0.001222	0.012585	9.7E-05
Litter	0.003705	0.000392	0.124405	0.039133	0.000477	0.108334	0.390791	0.006362
Roots	0.001122	0.000819	0.078231	0.045427	0.000306	0.207406	0.478415	0.010341

Tissue	V (kg/ha)	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
<b>Aboveground</b>								
Shrubs	1.35E-06	7.11E-07	1.67E-06	8.04E-07	6.3E-07	0.000104	0.000236	4.07E-07
Live Herbs	1.12E-06	0	1.77E-06	6.82E-06	1.2E-06	0.000431	0.00021	1.71E-07
Litter	0.000337	0.00031	0.00011	0.000105	4.23E-05	0.00362	0.005133	0.000149
Roots	7.33E-05	5.55E-05	0.000158	0.000176	6.57E-05	0.000756	0.003225	0.000124

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
<b>Aboveground</b>						
Shrubs	0	1.87E-06	2.59E-05		3.76E-06	8.94E-10
Live Herbs	1.37E-06	1.88E-06	3.86E-05		4.73E-06	1.33E-06
Litter	4.13E-06	5.52E-05	0.000214		0	1.45E-05
Roots	4.94E-06	4.55E-05	0.000348		0	0

Table 44. Emerald Lake Dry Meadows: Biomass and mineral capitals, whole-watershed basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
Live Herbs	62.90932			0.120986	0.01558	1.220698	0.666152	0.158534
Litter	49.69102			0.050482	0.032256	0.332001	0.282339	0.08219
Roots	361.3002	3.877955		3.663897	2.681342	5.641043	1.806505	0.579362

Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
Live Herbs	0.00144	0.000277	0.01887	0.019859	0.001755	0.027736	0.285671	0.002202
Litter	0.004212	0.000327	0.110131	0.033709	0.000606	0.107273	0.452215	0.008802
Roots	0.01229	0.008973	0.856803	0.497529	0.003353	2.271568	5.239733	0.113254

Tissue	V (kg/ha)	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
Live Herbs	2.54E-05	0	4.03E-05	0.000155	2.72E-05	0.009774	0.004766	3.89E-06
Litter	0.000338	0	0.000125	0.000194	5.94E-05	0.006117	0.005327	9.99E-05
Roots	0.000802	0.000608	0.001734	0.001928	0.00072	0.008279	0.035323	0.001359

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
Live Herbs	3.1E-05	4.28E-05	0.000876		0.000107	3.03E-05
Litter	8.42E-06	6.08E-05	0.000277		0	2.95E-05
Roots	5.41E-05	0.000498	0.003813			

Table 45. Emerald Lake Fell Fields: Biomass and mineral capitals, whole-watershed basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
Live Herbs	0.3598			0.000692	8.91E-05	0.006982	0.00381	0.000907
Litter	0.2842			0.000289	0.000184	0.001899	0.001615	0.00047
Roots	2.0664	0.022179		0.020955	0.015336	0.032263	0.010332	0.003314
Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
Live Herbs	8.23E-06	1.59E-06	0.000108	0.000114	1E-05	0.000159	0.001634	1.26E-05
Litter	2.41E-05	1.87E-06	0.00063	0.000193	3.46E-06	0.000614	0.002586	5.03E-05
Roots	7.03E-05	5.13E-05	0.0049	0.002846	1.92E-05	0.012992	0.029968	0.000648
Tissue	V (kg/ha)	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
Live Herbs	1.46E-07	0	2.3E-07	8.85E-07	1.55E-07	5.59E-05	2.73E-05	2.22E-08
Litter	1.93E-06	0	7.12E-07	1.11E-06	3.4E-07	3.5E-05	3.05E-05	5.71E-07
Roots	4.59E-06	3.48E-06	9.92E-06	1.1E-05	4.12E-06	4.73E-05	0.000202	7.77E-06
Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)		
Live Herbs	1.77E-07	2.45E-07	5.01E-06		6.14E-07	1.73E-07		
Litter	4.81E-08	3.48E-07	1.58E-06		0	1.69E-07		
Roots	3.09E-07	2.85E-06	2.18E-05					

Table 46. Emerald Lake Colluvium: Biomass and mineral capitals, whole-watershed basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
Live Herbs	1.473467			0.002834	0.000365	0.028591	0.015603	0.003713
Litter	1.163867			0.001182	0.000756	0.007776	0.006613	0.001925
Roots	8.4624	0.09083		0.085816	0.062803	0.132125	0.042312	0.01357

Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
Live Herbs	3.37E-05	6.5E-06	0.000442	0.000465	4.11E-05	0.00065	0.006691	5.16E-05
Litter	9.87E-05	7.65E-06	0.002579	0.00079	1.42E-05	0.002513	0.010592	0.000206
Roots	0.000288	0.00021	0.020068	0.011653	7.85E-05	0.053205	0.122725	0.002653

Tissue	V (kg/ha)	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
Live Herbs	5.96E-07	0	9.44E-07	3.63E-06	6.36E-07	0.000229	0.000112	9.11E-08
Litter	7.91E-06	0	2.92E-06	4.54E-06	1.39E-06	0.000143	0.000125	2.34E-06
Roots	1.88E-05	1.42E-05	4.06E-05	4.52E-05	1.69E-05	0.000194	0.000827	3.18E-05

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
Live Herbs	7.26E-07	1E-06	2.05E-05		2.51E-06	7.09E-07
Litter	1.97E-07	1.42E-06	6.49E-06		0	6.92E-07
Roots	1.27E-06	1.17E-05	8.93E-05			

Table 47. Emerald Lake Trees: Productivity and mineral fluxes, whole-watershed basis.

Tissue	Product.	N kg/ha/yr	S kg/ha/yr	P kg/ha/yr	Na kg/ha/yr	K kg/ha/yr	Ca kg/ha/yr	Mg kg/ha/yr
Needles	29.54432	0.32223	0.025585	0.027772	0.00185	0.118558	0.086838	0.03257
Live Br.	335.8824	2.050002	0.249169	0.268146	0.026296	2.021847	0.586572	0.396467
Stem Wood	108.5001	0.520801	0.061303	0.070525	0.005958	0.595123	0.075498	0.09586
Stem Bark	23.90066	0.177024	0.021957	0.022626	0.00243	0.156645	0.066848	0.035307
Litter	-9	-0.38658	-0.03069	-0.03332	-0.00222	-0.14223	-0.10418	-0.03907
Fine Roots	52.16878	0.242585			0.330112	0.119269	0.420422	0.064939
Woody Roots	173.8959	0.660805			0.748701	0.433183	0.994527	0.30729
Tissue	Zn kg/ha/yr	Cu kg/ha/yr	Fe kg/ha/yr	Mn kg/ha/yr	B kg/ha/yr	Al kg/ha/yr	Si kg/ha/yr	Ti kg/ha/yr
Needles	0.00059	0.000224	0.004394	0.008061	0.000894	0.010597	0.010879	7.75E-05
Live Br.	0.009504	0.002867	0.041744	0.039724	0.011466	0.076172	0.168104	0.001054
Stem Wood	0.002401	0.000775	0.00696	0.011854	0.003807	0.012872	0.018888	6.55E-05
Stem Bark	0.000824	0.000237	0.004408	0.003042	0.000793	0.008005	0.019763	0.000136
Litter	-0.00071	-0.00027	-0.00527	-0.00967	-0.00107	-0.01271	-0.01305	-9.3E-05
Fine Roots	0.000342	0.000717	0.08631	0.030241	0.00061	0.336605	0.711582	0.007538
Woody Roots	0.000938	0.001521	0.174244	0.099389	0.001509	0.53111	1.950796	0.011368
Tissue	V kg/ha/yr	Co kg/ha/yr	Ni kg/ha/yr	Mo kg/ha/yr	Cr kg/ha/yr	Sr kg/ha/yr	Ba kg/ha/yr	Li kg/ha/yr
Needles	6.19E-05	3.37E-05	4.7E-05	1.09E-05	2.63E-06	0.000384	0.000155	1.99E-05
Live Br.	0.000647	0.000175	0.00023	8.15E-05	9.72E-06	0.00381	0.001988	0.000174
Stem Wood	0.000207	0	2.73E-05	1.07E-05		0.000582	0.000218	4.74E-05
Stem Bark	4.64E-05	2.49E-05	2.67E-05	9.24E-06	1.38E-06	0.000414	0.000235	1.44E-05
Litter	-7.4E-05	-4E-05	-5.6E-05	-1.3E-05	-3.2E-06	-0.00046	-0.00019	-2.4E-05
Fine Roots	3.36E-06	4.33E-05	0.000107	0.000156	7.58E-05	0.000366	0.003274	3.73E-05
Woody Roots	7.43E-06	1.85E-05	0.000226	0.000354	0.000221	0.001221	0.008341	7.22E-05
Tissue	Ag kg/ha/yr	Sn kg/ha/yr	Pb kg/ha/yr	Be kg/ha/yr	Cd kg/ha/yr	As kg/ha/yr		
Needles	0	3.42E-05	0.000639	1.91E-07	2.41E-06	7.83E-07		
Live Br.	0	0.000384	0.00536	3.92E-06	5.53E-05	7.83E-06		
Stem Wood	0	0.000117	0.000966	1.81E-07	1.27E-05	1.45E-06		
Stem Bark	0	2.89E-05	0.00055	5.18E-07	5.08E-06	7.96E-07		
Litter	0	-4.1E-05	-0.00077	-2.3E-07	-2.9E-06	-9.4E-07		
Fine Roots	2.24E-05	7.62E-05	0.000143		6.49E-06	1.67E-05		
Woody Roots	0.000122	0.000232	0.000732		0	5.6E-05		

Table 48. Emerald Lake Willows  
whole-watershed basis.

## Productivity and mineral fluxes,

Tissue	Product.	N	S	P	NA	K	CA	MG
		kg/ha/yr						
Aboveground								
Salix								
New Leaves	1.58249	0.044626	0.00303	0.003007	7.33E-05	0.013799	0.017423	0.003197
New Twigs	1.293795	0.017466	0.001268	0.00207	2.39E-05	0.00693	0.005294	0.001508
New Wood	2.753992	0.017075	0.001707	0.002479	6.55E-05	0.004942	0.010487	0.001491
Reproductive	0.099507	0.001682	0.000127	0.000269	6.73E-06	0.000733	0.000221	0.000101
Old Twigs	40.89701	0.260378	0.02631	0.032718	0.000923	0.064881	0.139672	0.021221
Dead Wood	23.6232	0.122841	0.022206	0.004725	0.000392	0.049609	0.183552	0.018402
Shrubs	32.16828	0.269696	0.028287	0.024589	0.003732	0.209115	0.145472	0.033668
Live Herbs	16.93763	0.288171		0.027254	0.006551	0.363899	0.154461	0.039486
Litter	-102.17	-2.59268		-0.10254	-0.0124	-0.30677	-0.60359	-0.13546
Belowground								
0- 2mm Root	-164.018	-2.44386		-2.36185	-1.67061	-4.18491	-0.92898	-0.44941
2- 5mm Root	31.42125	0.270223		0.266718	0.127851	0.252554	0.219514	0.042283
5-10mm Root	191.235	1.663745		2.256573	2.738485	5.1796	0.626295	0.301195
10-20mm Root	116.7788			0.686075	0.129741	0.211953	0.475873	0.087993
20-50mm Root	238.1175							

Tissue	V	CO	NI	MO	CR	SR	BA	LI
	kg/ha/yr							
<b>Aboveground</b>								
<b>Salix</b>								
New Leaves	2.98E-07	3.64E-07	1.5E-07	8.81E-07	1.9E-07	8.88E-05	3.16E-05	2.89E-06
New Twigs	3.39E-07	1.53E-07	6.04E-08	7.76E-08	3.45E-08	4.26E-05	2.46E-05	1.49E-06
New Wood	7.11E-07	6.38E-07	8.49E-07	9.64E-08	2.48E-07	6.31E-05	5.68E-05	5.59E-06
Reproductive	1.31E-08	5.44E-08	5.14E-09	1.64E-08	2.16E-09	1.72E-06	9.23E-07	2.57E-07
Old Twigs	8.22E-06	9.13E-06	8.41E-06	1.86E-06	2.45E-06	0.00088	0.000871	0.000104
Dead Wood	4.64E-05	1.21E-05	7.95E-06	3.15E-07	2.05E-06	0.001146	0.001144	1.39E-05
Shrubs	1.34E-05	7.08E-06	1.66E-05	8.01E-06	6.28E-06	0.001033	0.002351	4.06E-06
Live Herbs	1.5E-06	1.45E-07	1.52E-05	5.89E-05	1.27E-05	0.00083	0.001165	1.23E-06
Litter	-0.00032	-0.00136	-3.8E-05	-9E-05	-3.4E-05	-0.00454	-0.00289	-0.00606
<b>Belowground</b>								
0- 2mm Root	-0.00062	-0.00035	-0.00106	-0.00126	-0.00054	-0.00651	-0.02192	-0.0014
2- 5mm Root	5.39E-05	3.36E-05	0.000122	0.000128	5.22E-05	0.001001	0.003644	5.57E-05
5-10mm Root	0.000469	0.00045	0.001158	0.001251	0.000365	0.002085	0.01462	0.00091
10-20mm Root	0.00011	0.00014	0.000323	0.000353	0.000127	0.001074	0.007591	0
20-50mm Root								

Tissue	AG	SN	PB	BE	CD	AS
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr
<b>Aboveground</b>						
<b>Salix</b>						
New Leaves	0	7.68E-07	1.73E-05	0	1.05E-07	0
New Twigs	0	1.07E-06	9.58E-06	2.16E-08	0	2.16E-09
New Wood	0	2.57E-06	2.06E-05	7.8E-08	0	0
Reproductive	1.66E-10	9.93E-08	8.96E-07	1.66E-09	2.06E-08	0
Old Twigs	0	3.98E-05	0.000295	1.18E-06	0	0
Dead Wood	0	1.5E-05	0.000219	0	0	0
Shrubs	0	1.86E-05	0.000258	0	3.74E-05	8.9E-09
Live Herbs	7.98E-06	9.9E-06	0.000175	6.17E-06	3.65E-05	3.3E-06
Litter	0	-8.9E-05	-0.00045	0	0	0
<b>Belowground</b>						
0- 2mm Root	-1.5E-06	-0.00021	-0.00377	0	-0.00433	-3.5E-05
2- 5mm Root	5.03E-06	4.05E-05	0.000239	0	0.000337	9.81E-06
5-10mm Root	0	0.000284	0.001473	0	0.002735	5.35E-05
10-20mm Root	5.02E-05	0.000169	0.000457	0	0.000806	4.44E-05
20-50mm Root						

Table 49. Emerald Lake Mesic Shrubs: Productivity and mineral fluxes, whole-watershed basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
New Leaves	1.400398	0.020866	0.001687	0.002381	6.92E-05	0.012155	0.007434	0.002231
New Twigs	0.405725	0.00426	0.000396	0.000669	6.4E-05	0.003694	0.002199	0.000487
Reproductive	0.049883	0.000579	6.04E-05	6.98E-05	1.76E-06	0.000377	0.000245	5.82E-05
Old Leaves	1.368065	0.014365	0.001395	0.001094	0.000651	0.012438	0.007032	0.002159
Old Twigs	3.860985	0.021622	0.002529	0.001737	0.000107	0.020399	0.013578	0.002698
Dead Wood	1.154537	0.007389	0.001178	0.000346	6.36E-05	0.004499	0.006773	0.00099
Litter	-9.13292	-0.12245		-0.0082	-0.00118	-0.0273	-0.02601	-0.00955
0- 2mm Roots	-13.6528	-0.20343		-0.1966	-0.13906	-0.34835	-0.07733	-0.03741
2- 5mm Roots	-3.74672	-0.03222		-0.0318	-0.01525	-0.03012	-0.02618	-0.00504
5-10mm Roots	-7.5993	-0.06611		-0.08967	-0.10882	-0.20583	-0.02489	-0.01197
10-20mm Roots	-3.96937			-0.02332	-0.00441	-0.0072	-0.01618	-0.00299
20-50mm Roots	0.932575							

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
New Leaves	0	9.41E-07	1.06E-05	0	1.26E-06	0
New Twigs	0	2.22E-07	3.25E-06	0	6.61E-07	0
Reproductive	0	3.14E-08	4.47E-07	0	2.44E-08	0
Old Leaves	0	5.13E-07	1.41E-05	0	3.97E-06	2.28E-09
Old Twigs	0	2.46E-06	2.69E-05	0	1.81E-06	0
Dead Wood	0	6.08E-07	1.08E-05	0	1.86E-06	0
Litter	0	-1.1E-05	-2.8E-05	0	0	0
0- 2mm Roots	-1.2E-07	-1.8E-05	-0.00031	0	-0.00036	-2.9E-06
2- 5mm Roots	-6E-07	-4.8E-06	-2.8E-05	0	-4E-05	-1.2E-06
5-10mm Roots	0	-1.1E-05	-5.9E-05	0	-0.00011	-2.1E-06
10-20mm Roots	-1.7E-06	-5.7E-06	-1.6E-05	0	-2.7E-05	-1.5E-06
20-50mm Roots						

Table 50. Emerald Lake Mesic Rock Crevices: Productivity and mineral fluxes, whole-watershed basis.

Tissue	Biomass	N	S	P	NA	K	CA	MG
	kg/ha/yr							
Live Shoot	11.39999	0.095576	0.010024	0.008714	0.001323	0.074107	0.051553	0.011931
Litter	-12.636	-0.16942			-0.01135	-0.00164	-0.03777	-0.03599
Roots	-38.7891	-0.16241			0	-0.17086	-0.13374	-0.30861
							-0.06721	-0.03021
Tissue	ZN	CU	FE	MN	B	AL	SI	TI
	kg/ha/yr							
Live Shoot	0.000207	7.28E-05	0.004456	0.004919	0.000193	0.005323	0.03944	0.000189
Litter	-0.00117	-0.00011	-0.03988	-0.00661	-0.00014	-0.02142	-0.06365	-0.00058
Roots	-0.00051	-0.00042	-0.03645	-0.02193	-0.00012	-0.12678	-0.23145	-0.00646
Tissue	V	OO	NI	MO	CR	SR	BA	LI
	kg/ha/yr							
Live Shoot	4.76E-06	2.51E-06	5.89E-06	2.84E-06	2.22E-06	0.000366	0.000833	1.44E-06
Litter	-1.2E-05	-0.00012	-8.1E-06	-4.3E-06	-4.3E-06	-0.00027	-0.00098	-5.8E-05
Roots	-4.2E-05	-2.7E-05	-7.9E-05	-9.2E-05	-3.7E-05	-0.00041	-0.00153	-9E-05
Tissue	AG	SN	PB	BE	CD	AS		
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr		
Live Shoot	0	6.6E-06	9.15E-05		0	1.33E-05	3.15E-09	
Litter	0	-1.5E-05	-3.8E-05		0	0	0	
Roots	-5.1E-07	-1.8E-05	-0.00023		0	-0.00029	-3.2E-06	

Table 51. Emerald Lake Wet Meadow Herbs: Productivity and mineral fluxes, whole-watershed basis.

Tissue	Product.	N kg/ha/yr	P kg/ha/yr	NA kg/ha/yr	K kg/ha/yr	CA kg/ha/yr	MG kg/ha/yr	ZN kg/ha/yr
--------	----------	---------------	---------------	----------------	---------------	----------------	----------------	----------------

Live Shoots	109.71	1.866566	0.176533	0.042433	2.357084	1.00049	0.255763	0.00235
Litter	-47.265	-0.72363	-0.04018	-0.04792	-0.34965	-0.23128	-0.07232	-0.00375
Roots	-314.329	-2.7661	-3.6764	-2.22189	-4.18561	-0.94697	-0.56307	-0.02548

Tissue	CU kg/ha/yr	FE kg/ha/yr	MN kg/ha/yr	B kg/ha/yr	AL kg/ha/yr	SI kg/ha/yr	TI kg/ha/yr	V kg/ha/yr
--------	----------------	----------------	----------------	---------------	----------------	----------------	----------------	---------------

Live Shoots	0.001178	0.044749	0.054104	0.006644	0.08361	0.634599	0.004145	9.7E-06
Litter	-0.00076	-0.14245	-0.05009	-0.00125	-0.17637	-0.54791	-0.00904	-7E-05
Roots	-0.03821	-0.87195	-0.13728	-0.00181	-2.40106	-5.11938	-0.10283	-0.00086

Tissue	CO kg/ha/yr	NI kg/ha/yr	MO kg/ha/yr	CR kg/ha/yr	SR kg/ha/yr	BA kg/ha/yr	LI kg/ha/yr	AG kg/ha/yr
--------	----------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------

Live Shoots	9.36E-07	9.82E-05	0.000382	8.2E-05	0.005373	0.007544	7.95E-06	5.17E-05
Litter	-2.3E-05	-0.00017	-0.00026	-9.8E-05	-0.00183	-0.0046	-0.00011	-7.7E-06
Roots	-0.00024	-0.00091	-0.00174	-0.00087	-0.01201	-0.02379	-0.00121	-3.5E-05

Tissue	SN kg/ha/yr	PB kg/ha/yr	BE kg/ha/yr	CD kg/ha/yr	AS kg/ha/yr
--------	----------------	----------------	----------------	----------------	----------------

Live Shoots	6.42E-05	0.001133	4E-05	0.000236	2.14E-05
Litter	-5E-05	-0.0002	-3.6E-06	0	-1.1E-05
Roots	-0.00041	-0.0045		-0.00916	-7.8E-05

Table 52. Emerald Lake Xeric Rock Crevices: Productivity and mineral fluxes, whole-watershed basis.

Tissue	Product.	N kg/ha/yr	S kg/ha/yr	P kg/ha/yr	NA kg/ha/yr	K kg/ha/yr	CA kg/ha/yr	MG kg/ha/yr
<b>Aboveground</b>								
Shrubs	0.998585	0.008372	0.000878	0.000763	0.000116	0.006491	0.004516	0.001045
Live Herbs	2.496477				0.004801	0.000618	0.048442	0.026435
Litter	-28.3901	-0.21419			-0.02015	-0.01353	-0.12661	-0.1151
Roots	-9.99588	-0.10729			-0.10137	-0.07418	-0.15607	-0.04998

Tissue	ZN kg/ha/yr	CU kg/ha/yr	FE kg/ha/yr	MN kg/ha/yr	B kg/ha/yr	AL kg/ha/yr	SI kg/ha/yr	TI kg/ha/yr
<b>Aboveground</b>								
Shrubs	1.81E-05	6.38E-06	0.00039	0.000431	1.69E-05	0.000466	0.003455	1.65E-05
Live Herbs	5.71E-05	1.1E-05	0.000749	0.000788	6.96E-05	0.001101	0.011337	8.74E-05
Litter	-0.00216	-0.00023	-0.07246	-0.02279	-0.00028	-0.0631	-0.2276	-0.00371
Roots	-0.00034	-0.00025	-0.0237	-0.01376	-9.3E-05	-0.06285	-0.14496	-0.00313

Tissue	V kg/ha/yr	CO kg/ha/yr	NI kg/ha/yr	MO kg/ha/yr	CR kg/ha/yr	SR kg/ha/yr	BA kg/ha/yr	LI kg/ha/yr
<b>Aboveground</b>								
Shrubs	4.17E-07	2.2E-07	5.16E-07	2.49E-07	1.95E-07	3.21E-05	7.3E-05	1.26E-07
Live Herbs	1.01E-06		0	1.6E-06	6.14E-06	1.08E-06	0.000388	0.000189
Litter	-0.0002	-0.00018	-6.4E-05	-6.1E-05	-2.5E-05	-0.00211	-0.00299	-8.7E-05
Roots	-2.2E-05	-1.7E-05	-4.8E-05	-5.3E-05		-2E-05	-0.00023	-0.00098

Tissue	AG kg/ha/yr	SN kg/ha/yr	PB kg/ha/yr	BE kg/ha/yr	CD kg/ha/yr	AS kg/ha/yr	
<b>Aboveground</b>							
Shrubs	0	5.79E-07	8.02E-06		0	1.16E-06	2.76E-10
Live Herbs	1.23E-06	1.7E-06	3.48E-05		4.26E-06	1.2E-06	
Litter	-2.4E-06	-3.2E-05	-0.00012		0	0	-8.4E-06
Roots	-1.5E-06	-1.4E-05	-0.00011				

Table 53. Emerald Lake Dry Meadows: Productivity and mineral fluxes, whole-watershed basis.

Tissue	Product.	N kg/ha/yr	S kg/ha/yr	P kg/ha/yr	NA kg/ha/yr	K kg/ha/yr	CA kg/ha/yr	MG kg/ha/yr
Live Herbs	56.66871			0.108984	0.014035	1.099605	0.60007	0.142808
Litter	-44.7617			-0.04547	-0.02906	-0.29907	-0.25433	-0.07404
Roots	-162.073	-1.73958		-1.64356	-1.2028	-2.53047	-0.81036	-0.25989

Tissue	ZN kg/ha/yr	CU kg/ha/yr	FE kg/ha/yr	MN kg/ha/yr	B kg/ha/yr	AL kg/ha/yr	SI kg/ha/yr	TI kg/ha/yr
Live Herbs	0.001297	0.00025	0.016998	0.017889	0.001581	0.024985	0.257333	0.001983
Litter	-0.00379	-0.00029	-0.09921	-0.03036	-0.00055	-0.09663	-0.40736	-0.00793
Roots	-0.00551	-0.00402	-0.38435	-0.22318	-0.0015	-1.01898	-2.35045	-0.0508

Tissue	V kg/ha/yr	CO kg/ha/yr	NI kg/ha/yr	MO kg/ha/yr	CR kg/ha/yr	SR kg/ha/yr	BA kg/ha/yr	LI kg/ha/yr
Live Herbs	2.29E-05	0	3.63E-05	0.000139	2.45E-05	0.008804	0.004293	3.5E-06
Litter	-0.0003	0	-0.00011	-0.00017	-5.3E-05	-0.00551	-0.0048	-9E-05
Roots	-0.00036	-0.00027	-0.00078	-0.00086	-0.00032	-0.00371	-0.01585	-0.00061

Tissue	AG kg/ha/yr	SN kg/ha/yr	PB kg/ha/yr	BE kg/ha/yr	CD kg/ha/yr	AS kg/ha/yr
Live Herbs	2.79E-05	3.85E-05	0.000789		9.67E-05	2.73E-05
Litter	-7.6E-06	-5.5E-05	-0.00025		0	-2.7E-05
Roots	-2.4E-05	-0.00022	-0.00171			

Table 54. Emerald Lake Fell Fields: Productivity and mineral fluxes, whole-watershed basis.

Tissue	Biomass (kg/ha)	N (kg/ha)	S (kg/ha)	P (kg/ha)	NA (kg/ha)	K (kg/ha)	CA (kg/ha)	MG (kg/ha)
Live Herbs	0.324108			0.000623	8.03E-05	0.006289	0.003432	0.000817
Litter	-0.25601			-0.00026	-0.00017	-0.00171	-0.00145	-0.00042
Roots	-0.92695	-0.00995		-0.0094	-0.00688	-0.01447	-0.00463	-0.00149

Tissue	ZN (kg/ha)	CU (kg/ha)	FE (kg/ha)	MN (kg/ha)	B (kg/ha)	AL (kg/ha)	SI (kg/ha)	TI (kg/ha)
Live Herbs	7.42E-06	1.43E-06	9.72E-05	0.000102	9.04E-06	0.000143	0.001472	1.13E-05
Litter	-2.2E-05	-1.7E-06	-0.00057	-0.00017	-3.1E-06	-0.00055	-0.00233	-4.5E-05
Roots	-3.2E-05	-2.3E-05	-0.0022	-0.00128	-8.6E-06	-0.00583	-0.01344	-0.00029

Tissue	V (kg/ha)	CO (kg/ha)	NI (kg/ha)	MO (kg/ha)	CR (kg/ha)	SR (kg/ha)	BA (kg/ha)	LI (kg/ha)
Live Herbs	1.31E-07	0	2.08E-07	7.97E-07	1.4E-07	5.04E-05	2.46E-05	2E-08
Litter	-1.7E-06	0	-6.4E-07	-1E-06	-3.1E-07	-3.2E-05	-2.7E-05	-5.1E-07
Roots	-2.1E-06	-1.6E-06	-4.4E-06	-4.9E-06	-1.8E-06	-2.1E-05	-9.1E-05	-3.5E-06

Tissue	AG (kg/ha)	SN (kg/ha)	PB (kg/ha)	BE (kg/ha)	CD (kg/ha)	AS (kg/ha)
Live Herbs	1.6E-07	2.2E-07	4.51E-06		5.53E-07	1.56E-07
Litter	-4.3E-08	-3.1E-07	-1.4E-06		0	-1.5E-07
Roots	-1.4E-07	-1.3E-06	-9.8E-06			

Table 55. Emerald Lake Colluvium: Productivity and mineral fluxes, whole-watershed basis.

Tissue	Product.	N kg/ha/yr	S kg/ha/yr	P kg/ha/yr	NA kg/ha/yr	K kg/ha/yr	CA kg/ha/yr	MG kg/ha/yr
--------	----------	---------------	---------------	---------------	----------------	---------------	----------------	----------------

Live Herbs	1.327299			0.002553	0.000329	0.025755	0.014055	0.003345
Litter	-1.04841			-0.00107	-0.00068	-0.007	-0.00596	-0.00173
Roots	-3.79607	-0.04074		-0.0385	-0.02817	-0.05927	-0.01898	-0.00609

Tissue	ZN kg/ha/yr	CU kg/ha/yr	FE kg/ha/yr	MN kg/ha/yr	B kg/ha/yr	AL kg/ha/yr	SI kg/ha/yr	TI kg/ha/yr
--------	----------------	----------------	----------------	----------------	---------------	----------------	----------------	----------------

Live Herbs	3.04E-05	5.85E-06	0.000398	0.000419	3.7E-05	0.000585	0.006027	4.65E-05
Litter	-8.9E-05	-6.9E-06	-0.00232	-0.00071	-1.3E-05	-0.00226	-0.00954	-0.00019
Roots	-0.00013	-9.4E-05	-0.009	-0.00523	-3.5E-05	-0.02387	-0.05505	-0.00119

Tissue	V kg/ha/yr	CO kg/ha/yr	NI kg/ha/yr	MO kg/ha/yr	CR kg/ha/yr	SR kg/ha/yr	BA kg/ha/yr	LI kg/ha/yr
--------	---------------	----------------	----------------	----------------	----------------	----------------	----------------	----------------

Live Herbs	5.37E-07	0	8.5E-07	3.27E-06	5.73E-07	0.000206	0.000101	8.21E-08
Litter	-7.1E-06	0	-2.6E-06	-4.1E-06	-1.3E-06	-0.00013	-0.00011	-2.1E-06
Roots	-8.4E-06	-6.4E-06	-1.8E-05	-2E-05	-7.6E-06	-8.7E-05	-0.00037	-1.4E-05

Tissue	AG kg/ha/yr	SN kg/ha/yr	PB kg/ha/yr	BE kg/ha/yr	CD kg/ha/yr	AS kg/ha/yr
--------	----------------	----------------	----------------	----------------	----------------	----------------

Live Herbs	6.54E-07	9.03E-07	1.85E-05		2.26E-06	6.38E-07
Litter	-1.8E-07	-1.3E-06	-5.8E-06		0	-6.2E-07
Roots	-5.7E-07	-5.2E-06	-4E-05			